

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LABORATORY TESTS TO REFINE THE MAXIMUM
DENSITY PROCEDURE FOR COHESIONLESS
SOILS USING A VIBRATORY TABLE

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Soils Engineering Branch
DIVISION OF RESEARCH



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ABSTRACT

To improve the test procedure for determining the maximum laboratory dry density of cohesionless soils, time of vibration, initial dry density, amplitude and frequency of vibration, and the moisture condition of the material were investigated. Changes in the gradation during vibration increased both the minimum and maximum dry densities of a weakly-cemented dune sand. The increase in density was insignificant for times of vibration greater than 6 minutes except for the weakly-cemented material. The initial density of the soil prior to vibration did not have a significant effect on the final density. No conclusions could be drawn as to the effect of the amplitude and frequency of vibration on the dry density from the results using two electromagnetic vibrators and one eccentric weight vibrator. The difference between the densities obtained using oven-dried soil and initially saturated soil was not significant for the two soils tested: a poorly graded sand and gravel, 3-inch maximum-size, and a poorly graded fine sand. The results did not suggest any revisions which would improve the Bureau's current method for determining the maximum laboratory density of cohesionless soils.

DESCRIPTORS-- *vibrators/ electrical/ vibrations/ *relative density/
*soil compaction/ *noncohesive soils/ dry density/ test procedures/
sands/ time/ dry condition/ gravel/ soil moisture/soil investigations/
soil mechanics/ soil tests/ *laboratory equipment/ research and
development/ graphical analysis/ dune sand/ saturation
IDENTIFIERS-- amplitudes/ surcharge/ frequency/ electromagnetic vibrators/
eccentric weight vibrators

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Subject: Laboratory tests to refine the maximum density procedure
for cohesionless soils using a vibratory table

INTRODUCTION

The Bureau of Reclamation has used the relative density of cohesionless soils to control compaction since about 1950. The relative density method of control specifies the required field density as a percentage of the range between the minimum and maximum density of the soil as determined in the laboratory.¹/* Therefore, it is desirable to have a standard procedure for obtaining the maximum and minimum densities. Experience has shown that a reasonable amount of care in the laboratory will insure determination of a suitable value for the minimum density.²/ However, the maximum density of cohesionless soil appears to be extremely sensitive to the details of the test procedures.^{2,3}/

Based on the results of previous investigations, the Bureau of Reclamation has established an alternate procedure for determining the maximum density of cohesionless soil. This procedure utilizes a vibratory table and has been adopted for Bureau-wide use.¹/ The alternate procedure appears to give satisfactory maximum densities for most of the soils encountered in Bureau projects, but occasionally some projects have reported relative densities greater than 100 percent when the maximum density was obtained by the vibratory table method.

Since by definition the maximum density used in the relative density method of control should exceed the density which can be obtained by the field equipment, it was felt that additional research was needed to improve the laboratory procedure. Previous investigations^{3,4}/ by the Bureau and a cooperative investigation²/ sponsored by ASTM have indicated that table-type vibrators most often give the maximum densities for cohesionless soils. However, the mechanisms which affect the densification of soils subject to vibrations are poorly understood. In

*Refer to references at end of report.

this investigation an attempt has been made to isolate and determine the direction and magnitude of some of the factors believed to affect the maximum density obtained by a vibratory table. Variables considered in this investigation were: (1) time of vibration, (2) density before vibration, (3) amplitude and frequency of vibration, and (4) moisture condition of material (ovendried or initially saturated).

EQUIPMENT

The following major items of equipment were used in this research:

a. Cylindrical unit weight measures of the capacity and dimensions given in the tabulation below:

Volume		Inside				Thickness				Material
		Diameter		Height		Wall		Bottom		
Cu ft	Cu m	In.	Cm	In.	Cm	In.	Cm	In.	Cm	
0.1	.0028	6	15.2	6	15.2	5/16	.79	5/16	.79	Cast silicon
0.5	.0142	11	27.9	9	22.9	5/16	.79	5/16	.79	aluminum
										ASTM-SG-704

b. Vibrator No. 9--Electromagnetic table-type vibrator, frequency 3,600 cpm, net weight 116 pounds (52.6 kg), 230-v power supply. The amplitude can be varied by a rheostat graduated from 0 to 100. The graduations on the rheostat are not directly correlated with the power supplied to the vibrator.

c. Vibrator No. 10--Electromagnetic table-type vibrator, frequency 3,600 cpm, net weight 45 pounds (20.4 kg), 230-v power supply. The amplitude can be varied by a rheostat graduated from 0 to 100. The graduations on the rheostat are not directly correlated with the power supplied to the vibrator.

d. Vibrator No. 11--Eccentric weight-type vibrator attached to a shop-made table. The amplitude and frequency could be varied by a rheostat graduated from 0 to 120 volts, but vibration was not detectable for a setting less than 40 volts. The amplitude and frequency could not be varied independently.

e. Single-piece guided deadweight surcharge equal to 2 psi (.14 kg/cm²) for the two measure sizes.

f. A specially mounted dial gage for determining the volume of the specimen after vibration.

SOILS

The following three soils were used in this investigation:

Soil No.	Description	Source
24N-339	Poorly graded fine sand 10 percent fines (dune sand)	Norton, Kansas
7	Poorly graded sand and gravel, 3-inch (7.6-cm) maximum-size, no fines	South Platte River, Denver, Colorado (artificial gradation)
10	Poorly graded fine sand 10 percent fines	Cherry Creek, Denver, Colorado (artificial gradation)

The Soils No. 7 and 10 correspond to numbers used to designate these soils in previous investigations of relative density.^{3,4} The gradations of the three soils are shown in Figures 1, 2, and 3. A limited number of tests were run on Soils No. 1, 2, 3, 4, 6, 7, and 9. These tests are discussed in Appendix A.

TEST PROCEDURE

Minimum Density

Ovendried material was placed as loosely as possible in a measure as shown in Figure 4 and the excess carefully struck off. The pouring device and measure were selected according to the maximum size soil particles as given in the following tabulation:

Maximum size :			Unit weight		
soil particle :			Pouring device used for :		
In. : cm :			minimum density tests :		
			Cu ft : Cu m		
3	7.6	Shovel or large scoop	0.5	.0142	
1-1/2	3.8	Scoop	0.1	.0028	
3/8	1.0	1-inch (2.5-cm) spout	0.1	.0028	
No. 4	0.5	1/2-inch (1.3-cm) spout	0.1	.0028	

The minimum density procedure was not investigated in this research, but was used to control the initial placement condition for most of the maximum density tests.

Maximum Density

Two sizes of electromagnetic vibrators attached to commercially supplied tables, Vibrators No. 9 and 10, shown in Figures 5 and 6, respectively, were used for this series of tests on a poorly graded sand and gravel with 3-inch (7.6-cm) maximum-size (Soil No. 7), a natural dune sand (Soil No. 24N-339), and a poorly graded fine sand (Soil No. 10). An eccentric weight electric motor attached to a shop-made table, Vibrator No. 11 shown in Figure 7, was used for additional tests on Soils No. 7 and 10.

A limited number of tests were run using a sieve shaker as a vibrator. The results of these tests are discussed and compared with densities obtained with other vibrators in Appendix B.

Before actual testing of soil specimens, some preliminary tests were run to determine the frequency and amplitude characteristics of the vibrators under various loads in the range commonly used in vibrating the soil specimens. The details of these tests are presented in Appendix C.

The rheostat settings were varied from 30 to 100 on the electromagnetic vibrators to study the effect of the amplitude of vibration on the soil density obtained. The rheostat settings were varied from 70 to 120 on the eccentric weight electric motor vibrator to study the effect of the frequency of vibration on the soil density.

A 2-psi (.14 kg/cm²) deadweight surcharge was used as shown in Figure 8 for all tests. The 0.1-cubic-foot measure was used for all tests on Soils No. 24N-339 and 10, and the 0.5-cubic-foot measure was used for all tests on Soil No. 7.

The average height of the soil was obtained by dial gage readings on opposite sides of the surcharge baseplate as shown in Figure 9. Using

this information and the cross-sectional area of the measure, the volume of the specimen after vibration was computed.

Most of the tests were run on oven-dried soil, but a few were run with initially saturated soil using the rheostat setting which produced the highest density on the dried soil. The tests on the initially saturated specimens were run for a total of 20 minutes with density determinations every 4 minutes.

A total time of vibration of 16 minutes, with density determinations made every 4 minutes, was used for the tests to study the effect of amplitude, frequency, and time of vibration on the soil density.

The effect of placing the soil at various densities before the start of vibration was investigated by placing the specimens at minimum density, minimum plus 5 pcf (.08 gm/cc) and minimum plus 10 pcf (.16 gm/cc). These specimens were vibrated a total of 12 minutes; densities were determined at 1, 3, 5, 7, 9, and 12 minutes after the test began. All tests on Soils No. 7 and 10 were run in duplicate, but only single tests were run on Soil No. 24N-339.

A quantity of soil equal to about twice the amount required for a single test was prepared for Soils No. 7 and 10. After each test the entire quantity of soil was mixed and then the amount required for the following test was taken from the sample. For Soil No. 24N-339 a quantity slightly greater than that required to fill the 0.1-cubic-foot measure was taken from a sack sample. This quantity was then used for all tests, except that it was once necessary to add more material to the original quantity to fill the 0.1-cubic-foot measure. The maximum density may be significantly affected by repeated vibration of a sample of material.

A grain-size analysis was performed for each of the three soils before and after the testing program to determine the effect of vibration on the grain-size distribution.

Variations in Test Procedure for Tests on Soil No. 24N-339

The rheostat settings and times of vibration described above were not used for tests on Soil No. 24N-339. In these tests a sample was vibrated according to the following tabulation without being removed from the table.

Rheostat setting	:	Increment of time	:	Cumulative time
	:		:	
100	:	8	:	8
100	:	4	:	12
90	:	8	:	20
80	:	8	:	28
80	:	4	:	32
70	:	8	:	40
60	:	8	:	48
60	:	4	:	52
50	:	8	:	60
40	:	8	:	68
40	:	4	:	72
	:		:	

Density determinations were made after each entry in the above table. Vibrators No. 9 and 10 were used.

Tests were run at rheostat settings varied from 50 to 90 in increments of 10 for a total of 12 minutes at each setting with density determination after 8 and 12 minutes. The soil was removed from the measure and mixed with the original sample after the run at each rheostat setting. These tests were performed on Vibrator No. 9 only.

A test was run at a rheostat setting of 80 for 36 minutes and at a rheostat setting of 60 for 60 minutes with density determinations every 4 minutes on Vibrator No. 9. Similar tests were run at rheostat settings of 100 and 80 on Vibrator No. 10.

Tests on a Sieve Shaker

A few tests were run to investigate the feasibility of a sieve shaker as a vibrator for obtaining the maximum density of cohesionless soils. These data are presented in Appendix B.

DISCUSSION OF TEST RESULTS

The load-amplitude relationship for each of the three vibrators using the maximum rheostat setting is shown in Figure 10. For the electromagnetic vibrators (Nos. 9 and 10) the amplitude generally decreased as the load on the vibrating table was increased. The amplitude of the eccentric weight vibrator was independent of the load.

The amplitude-rheostat setting relationship of each of the three vibrators for loads of 100 and 250 lbs (consisting of loose steelplates on the vibrating table) is shown in Figure 11. The loads of 100 and 250 lbs (45.4 and 90.7 kg) are approximately equal to the loads on the vibrating table during actual testing of the soil samples. The amplitude generally increased with increasing rheostat settings for the electromagnetic vibrators, but was constant for the eccentric weight vibrator. The amplitude-rheostat settings relationship is shown in Figure 11B for the single-piece 2-psi surcharge weight (264 lbs) and the 0.5-cubic-foot measure. The amplitude of vibration for the 250-lb load and the 264-lb load was significantly different due to the use of a loose plate load or a single piece load.

The frequency (constant 3,600 cpm) of the electromagnetic vibrators was independent of the rheostat settings and of loads in the range from 0 to 300 pounds (0 to 136.1 kg). The frequency of the eccentric weight vibrator varied with the rheostat setting as shown in Figure 12, but the frequency was independent of the load. A more complete discussion of the characteristics of the vibrators is given in Appendix C.

Tests on a Natural Dune Sand

The intended purpose of this group of tests was to investigate the effect of the amplitude on the maximum density obtained and to compare two sizes of electromagnetic table-type vibrators (Vibrators No. 9 and 10) for efficiency in obtaining the maximum density of this soil.

As shown in the following discussion, the gradation of Soil No. 24N-339 was probably changing continuously with time of vibration; therefore, no attempt is made to evaluate the effect of the amplitude of vibration on the maximum density nor to compare the two vibrators for efficiency. However, the data from these tests do serve to illustrate the effect of changes in gradation (for one soil) on the minimum and maximum density. Further investigation is needed to determine the relationship between soil gradation and the minimum and maximum density.

The results of tests on Soil No. 24N-339, using Vibrators No. 9 and 10, are presented in Tables 1 and 2 respectively. The significant feature of these tests is the change in minimum density with time of vibration as shown in Figure 13 where the maximum and minimum densities of this soil are plotted as a function of the total time of vibration and the rheostat setting. The soil was removed and mixed with the original sample at each point on the minimum density curve in Figure 13. A visual inspection of a sample of Soil No. 24N-339, which had not been vibrated, revealed a presence of numerous agglomerations which could be reduced to individual grains by slight pressure between the fingers. The increase in the minimum density with vibration is attributed to the breakdown of a weak cement present in the material.

The breakdown of Soil No. 24N-339 due to vibration is illustrated in Figure 1. In Figure 1, Curve A represents the gradation of Soil No. 24N-339 obtained by shaking 10 minutes on the sieve shaker before vibration in the maximum density test; Curve B represents the gradation obtained by this same method after the sample had been vibrated for about 300 minutes in the maximum density test; and Curve C represents the gradation obtained by the standard procedure using a mechanical disperser. The actual gradation when the first minimum density was poured was probably coarser than represented by Curve A of Figure 1 because many of the agglomerates were broken down during the shaking for 10 minutes with the sieve shaker.

Tests on Two Artificially Prepared Soils

To avoid the problem of changing soil gradation during vibration, two cohesionless soils were prepared to represent a wide range in gradation. Soil No. 7 was prepared by mixing selected sizes from sand and gravel obtained from the South Platte River near Denver, Colorado. Soil No. 10 was prepared to have a gradation similar to Soil No. 24N-339 by mixing selected sizes from Cherry Creek sand. The gradations of Soils No. 7 and 10 in Figures 2 and 3, respectively, are designated "before" and "after" to indicate the change in gradation during the testing program. It is obvious from Figures 2 and 3 that the gradation of the artificially prepared soils changed somewhat during testing.

The results of maximum density tests on a poorly graded sand and gravel (Soil No. 7) using Vibrators No. 9, 10, and 11 are presented in Tables 3, 4, and 5, respectively, and the results for a poorly graded fine sand (Soil No. 10) are presented in Tables 6, 7, and 8.

The results of a group of tests to determine the required time of vibration are presented in Figures 14A and B. The data indicate that the increase in density after about 6 minutes is negligible. These tests were also used to observe the reproducibility of the results and to check the possibility of binding of the surcharge baseplate against the sides of the measure. The two tests represented by closed circles in Figure 14A, were run by the same operator on the same date, and the two tests represented by closed squares were run by different operators and at times near the beginning and the end of the investigation. These limited data indicate a reproducibility of approximately 1 pcf (.016 gm/cc). For the data presented in Figure 14B, the surcharge baseplate was removed and resealed at each point represented by the open symbols, but was not disturbed in the tests represented by the solid symbols. The data seem to eliminate the possibility of binding of the surcharge baseplate as a factor influencing the maximum density.

The effect of the initial density (density before vibration) on the maximum density of Soils No. 7 and 10 (obtained by a vibration time of

12 minutes on Vibrators No. 9, 10, and 11) is shown in Figures 15A and B. Tests were performed at initial densities equal to the minimum, minimum plus 5 pcf (.08 gm/cc), and minimum plus 10 pcf (.16 gm/cc). The densities equal to minimum plus 5 pcf and to the minimum plus 10 pcf were obtained by tapping the side of the measure until the desired amount of soil could be added. The soil and measure were then placed on the vibrating table and vibrated a total of 12 minutes. The effect of the initial density on the maximum density does not appear to be significant for either Soil No. 7 or 10.

The results of a group of tests to investigate the effect of amplitude and frequency on the maximum density are presented in Figures 16A and B where the dry density obtained by vibrating for 16 minutes is shown as a function of the rheostat setting. The rheostat setting was varied from 30 to 100 in increments of 10 for the electromagnetic vibrators (Vibrators No. 9 and 10). In this range of rheostat settings, the frequency was constant at 3,600 cpm and the amplitude varied as shown in Figures 11A and B. The rheostat setting was varied from 70 to 120 on the eccentric weight vibrator (Vibrator No. 11). In this range of rheostat settings the amplitude of vibration was constant as shown in Figures 11A and B, and the frequency varied as shown in Figure 12. For Soil No. 7, the three vibrators gave similar maximum densities with erratic variation within a range of approximately 4 pcf. For Soil No. 10 the three vibrators gave nearly identical maximum densities at rheostat settings greater than 60 for Vibrators No. 9 and 10 and settings greater than 80 for Vibrator No. 11. At rheostat settings less than 60, the density for Soil No. 10, obtained using Vibrator No. 9 increased slightly but the density obtained using Vibrator No. 10 decreased rapidly. The density obtained for Soil No. 10, using Vibrator No. 11, decreased rapidly for rheostat setting less than 80.

The limited data presented in Figures 11, 12, and 16 indicate:

(1) The density obtained by vibration is independent of the frequency in the range 3,600 cpm to 8,400 cpm at an amplitude of approximately .005 inch (.013 cm), but drops rapidly for frequencies immediately below 3,600 cpm.

(2) The density obtained by vibration is independent of the amplitude in the range from .010 to .020 inch (.025 to .051 cm) at a frequency of 3,600 cpm, but drops rapidly for amplitudes less than .010 inch (.025 cm) or is very erratic at amplitudes in the range .005 to .010 inch (.013 to .025 cm).

It should be emphasized that (1) and (2) are not based on sufficient data to qualify as conclusions, but are listed here only as possible aids in future research to determine the effect of amplitude and frequency on the soil density.

Tests using initially saturated material were performed for all combinations of Soils No. 9 and 10 and Vibrators No. 9, 10, and 11. The differences in the densities obtained using oven-dried and initially saturated material were not considered significant for the conditions tested.

CONCLUSIONS AND RECOMMENDATIONS

The increase in density was insignificant for times of vibration greater than about 6 minutes for the soils and equipment used in this investigation. The vibration time of 8 minutes required by the current Bureau of Reclamation procedure* is a reasonable and sufficient time when equipment similar to Vibrators No. 9 and 10 are used.

The initial density (before vibration) did not have a significant effect on the final density obtained by a vibration time of 12 minutes. The minimum density procedure should be used to fill the measure for maximum density tests because this procedure helps provide a representative sample in the measure and minimizes segregation before the start of vibration.

There was evidence that the amplitude and frequency of the vibrating instrument affected the results indicating that certain limiting ranges for operation are recommended. For the equipment and soil used in this research, the maximum density was nearly independent of frequency in the range 3,600 to 8,400 cpm at an amplitude of .005 inch (.013 cm) and is nearly independent of amplitude in the range .010 to .020 inch (.025 to .051 cm) at a frequency of 3,600 cpm. Further research in which the frequency or amplitude is held constant while the other is varied over a wide range is needed to clarify the effect of these variables on the soil density obtained by vibration.

The difference between the densities obtained using oven-dried soil and initially saturated soil was not significant for the two soils tested. The data available at this time do not allow a reliable correlation between soil gradation and the appropriate moisture condition; therefore the maximum density of an unfamiliar soil should be determined using both oven-dried and initially saturated material.

Changes in the gradation of a weakly cemented dune sand during vibration were found to increase both the minimum and maximum densities obtained for this material.

The current method for determining the maximum density of cohesionless soils was developed during the preliminary phases of this study and as a result of previous progress reports. The research of this study gives greater confidence in the procedure and provides information for several questions of possible variables that affect the results. Although the general procedure appears satisfactory, certain limiting ranges of operation for the vibrators were indicated. The possibility of inaccuracies in the volume determination of the density test hole in the field is suggested as a contributing cause for reported field densities of more than 100 percent relative density, and special care should be given to this problem in control testing.

*Designation E-12B 1/

BIBLIOGRAPHY

1. U.S. Bureau of Reclamation, Earth Manual, First Edition, Revised 1963, p 474 through 474j
2. Felt, Earl J., "Laboratory Method of Compacting Granular Material," American Society for Testing and Materials, Special Technical Publication No. 239, 1958, p 89
3. U.S. Bureau of Reclamation, "Development of a Maximum Density Test for Cohesionless Soil by a Vibratory Method," Earth Laboratory Report No. EM-557, Denver, Colorado, May 8, 1961
4. Pettibone, H. C., and J. Hardin, "Research on Vibratory Maximum Density Test for Cohesionless Soils," presented at the Symposium on "Compaction of Soils," 67th Annual Meeting of the American Society for Testing and Materials, June 21-26, 1964

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Table 1

RESULTS OF TESTS ON A NATURAL DUNE SAND--24N-339--AUGUST 1963
Electromagnetic Vibrator No. 9, 0.1-cu-ft Measure
2-psi Single-piece Surcharge, Frequency = 3,600 cpm

Time of vibration, min		Rheostat setting,	Amplitude of vibration,	Initial density,	Final density,
Increase	Total	percent	inch	pcf	pcf
:	:	:	:	:	:
8	8	100	.011	88.4	112.82
4	12	100	.011	:	115.36
8	20	90	.011	:	115.97
8	28	80	.010	:	117.51
4	32	80	.010	:	118.45
8	40	70	.008	:	118.45
8	48	60	.006	:	118.77
4	52	60	.006	:	118.77
8	60	50	.006	:	118.61
8	68	40	-	:	118.92
4	72	40	-	:	118.77
8	8	90	:	93.94	114.82
4	12	90	:	:	115.38
8	8	80	:	95.23	116.26
4	12	80	:	:	116.40
8	8	70	:	96.02	116.10
4	12	70	:	:	116.67
8	8	60	:	96.92	116.77
4	12	60	:	:	117.61
8	8	50	:	96.42	112.79
4	12	50	:	:	113.58
8	8	80	:	95.83	116.85
4	12	80	:	:	117.70
4	16	80	:	:	117.50
4	20	80	:	:	117.93
4	24	80	:	:	118.37
4	28	80	:	:	118.66
4	32	80	:	:	118.81
4	36	80	:	:	118.96
8	8	60	.006	96.48	115.20
4	12	60	:	:	115.89
4	16	60	:	:	116.45
4	20	60	:	:	116.59
4	24	60	:	:	116.87
4	28	60	:	:	117.15
4	32	60	:	:	117.43
4	36	60	:	:	117.72
4	40	60	:	:	118.00
4	44	60	:	:	118.29
4	48	60	:	:	118.44
4	52	60	:	:	118.73
4	56	60	:	:	118.58
4	60	60	:	:	119.02

Table 2

RESULTS OF TESTS ON A NATURAL DUNE SAND--No. 24N-339--AUGUST 1963
 Electromagnetic Vibrator No. 10, 0.1-cu-ft Measure
 2-psi Single-piece Surcharge, Frequency = 3,600 cpm

Time of vibration, min		Rheostat setting,	Amplitude of vibration,	Initial density,	Final density,
Increase	Total	percent	inch	pcf	pcf
8	8	100	.027	96.42	119.04
4	12	100			119.18
8	20	90	.027		119.36
8	28	80	.021		119.95
4	32	80			119.95
8	40	70	.021		120.40
8	48	60	.006		121.61
4	52	60			121.76
8	60	50	.006		122.07
8	68	40	.004		121.76
4	72	40			121.91
8	8	100		97.12	120.05
4	12	100			120.34
4	16	100			120.64
4	20	100			120.79
4	24	100			120.94
4	28	100			121.09
4	32	100			120.94
4	36	100			121.09
8	8	80		97.71	119.90
4	12	80			120.05
4	16	80			120.20
4	20	80			120.20
4	24	80			120.34
4	28	80			120.34
20	20	80	Initially saturated; final moisture = 11.23%		116.89

Table 3

RESULTS OF TESTS ON A POORLY GRADED SAND AND GRAVEL--NO. 7--JANUARY 1964
Electromagnetic Vibrator No. 9, 0.5-cu-ft Measure
2-psi Single-piece Surcharge, Frequency = 3,600 cpm

2-psi Single-piece Surcharge, Frequency - 2,000 cpm											
Time of vibration, min		:	Rheostat setting, percent	:	Initial density, pcf	:	Moisture, final percent	:	Dry density, pcf	:	Av dry density, pcf
<u>1/</u> (1)	1	:	100	:	118.0	:	Ovendry	:	135.7	:	135.4
	3	:	100	:		:		:	136.4	:	136.1
	5	:	100	:		:		:	136.5	:	136.1
	7	:	100	:		:		:	136.8	:	136.6
	9	:	100	:		:		:	136.9	:	136.7
	12	:	100	:		:		:	137.3	:	137.0
<u>1/</u> (2)	1	:	100	:	117.8	:	Ovendry	:	135.0	:	
	3	:	100	:		:		:	135.8	:	
	5	:	100	:		:		:	135.7	:	
	7	:	100	:		:		:	136.3	:	
	9	:	100	:		:		:	136.5	:	
	12	:	100	:		:		:	136.7	:	
(1)	12	:	100	:	123.0	:	Ovendry	:	137.2	:	136.6
		:		:	min+5	:		:		:	
(2)	12	:	100	:	123.0	:	Ovendry	:	136.1	:	
		:		:	min+5	:		:		:	
(1)	12	:	100	:	128.0	:	Ovendry	:	135.3	:	135.8
		:		:	min+10	:		:		:	
(2)	12	:	100	:	128.0	:	Ovendry	:	136.3	:	
		:		:	min+10	:		:		:	
(1)	16	:	100	:	117.7	:	Ovendry	:	136.2	:	136.2
(2)	16	:	100	:	117.9	:	Ovendry	:	136.2	:	
(1)	16	:	90	:	114.1	:	Ovendry	:	133.4	:	133.2
(2)	16	:	90	:	116.9	:	Ovendry	:	133.1	:	
(1)	16	:	80	:	117.3	:	Ovendry	:	134.2	:	133.8
(2)	16	:	80	:	116.1	:	Ovendry	:	133.1	:	
(1)	16	:	70	:	117.3	:	Ovendry	:	135.7	:	135.6
(2)	16	:	70	:	120.1	:	Ovendry	:	135.5	:	
(1)	16	:	60	:	117.3	:	Ovendry	:	128.0	:	134.0
(2)	16	:	60	:	116.3	:		:	135.5	:	
(1)	16	:	50	:	116.1	:	Ovendry	:	132.2	:	134.1
(2)	16	:	50	:	117.5	:		:	136.0	:	
(1)	16	:	40	:	116.5	:	Ovendry	:	133.0	:	133.8
(2)	16	:	40	:	112.1	:		:	133.1	:	
(1)	16	:	30	:	116.9	:	Ovendry	:	131.6	:	132.3
(2)	16	:	30	:	119.7	:		:	133.0	:	
(1)	20	:	100	:	-	:	6.9	:	135.7	:	-
(1)	20	:	70	:	-	:	7.6	:	132.5	:	133.6
(2)	20	:	70	:	-	:	7.3	:	134.7	:	

1/Nos. (1) and (2) indicate duplicate samples.

Table 4

RESULTS OF TESTS ON A POORLY GRADED SAND AND GRAVEL--NO. 7--JANUARY 1964
 Electromagnetic Vibrator No. 10, 0.5-cu-ft Measure
 2-psi Single-piece Surcharge, Frequency = 3,600 cpm

Time of vibration, min		Rheostat setting, percent	Initial density, pcf	Moisture, final percent	Dry density, pcf	Av dry density, pcf
<u>1</u> / (1)	1	100	114.1	Ovendry	131.7	131.8
	2	100			133.0	132.8
	4	100			133.0	133.0
	6	100			133.0	133.1
	8	100			132.3	132.7
	10	100			132.7	133.0
	12	100			132.7	133.0
<u>1</u> / (2)	1	100	118.1	Ovendry	131.9	
	3	100			132.5	
	5	100			133.0	
	7	100			133.1	
	9	100			133.2	
	12	100			133.3	
(1)	12	100	123.0	Ovendry	132.2	133.2
			min+5			
(2)	12	100	123.0	Ovendry	134.2	
			min+5			
(1)	12	100	128.0	Ovendry	132.5	132.8
			min+10			
(2)	12	100	128.0	Ovendry	133.0	
			min+10			
(1)	16	100	117.3	Ovendry	134.4	134.0
(2)	16	100	117.3		133.7	
(1)	16	90	116.1	Ovendry	132.8	133.4
(2)	16	90	117.3		133.9	
(1)	16	80	118.1	Ovendry	134.5	133.6
(2)	16	80	119.3		132.8	
(1)	16	70	118.5	Ovendry	133.4	133.6
(2)	16	70	118.5		133.7	
(1)	16	60	117.9	Ovendry	131.9	131.4
(2)	16	60	118.1		130.9	
(1)	16	50	118.5	Ovendry	133.1	132.6
(2)	16	50	118.5		132.2	
(1)	20	100	-	6.9	134.9	134.2
(2)	20	100	-	7.6	133.6	

1/Nos. (1) and (2) indicate duplicate samples.

Table 5

RESULTS OF TESTS ON A POORLY GRADED SAND AND GRAVEL--NO. 7--JANUARY 1964
 Eccentric-weight-type Vibrator No. 11, 0.5-cu-ft Measure
 2-psi Single-piece Surcharge--Variable Frequency

Time of vibration, min		Rheostat setting, volts	Initial density, pcf	Moisture, final percent	Dry density, pcf	Av dry density, pcf
<u>1/</u> (1)	1	120	117.4	Ovendry	133.3	133.3
	3	120			133.8	134.0
	5	120			134.1	134.3
	7	120			134.2	134.4
	9	120			134.5	134.7
	12	120			134.5	134.8
<u>1/</u> (2)	1	120	117.6	Ovendry	133.3	
	3	120			134.2	
	5	120			134.5	
	7	120			134.7	
	9	120			134.9	
	12	120			135.0	
(1)	12	120	123.0	Ovendry	135.1	135.2
			min+5			
(2)	12	120	123.0	Ovendry	135.3	
			min+5			
(1)	12	120	128.0	Ovendry	136.3	136.4
			min+10			
(2)	12	120	128.0	Ovendry	136.5	
			min+10			
(1)	16	120	118.9	Ovendry	136.3	136.0
(2)	16	120	118.9	Ovendry	135.7	
(1)	16	110	117.7	Ovendry	135.0	135.4
(2)	16	110	118.5	Ovendry	135.9	
(1)	16	100	117.1	Ovendry	133.1	134.2
(2)	16	100	117.4	Ovendry	135.4	
(1)	16	90	117.9	Ovendry	131.9	132.3
(2)	16	90	117.9	Ovendry	132.7	
(1)	16	80	118.3	Ovendry	134.7	135.0
(2)	16	80	118.3	Ovendry	135.3	
(1)	16	70	119.5	Ovendry	133.4	132.6
(2)	16	70	119.5	Ovendry	131.9	
	20	120	-	7.4	133.5	-

1/Nos. (1) and (2) indicate duplicate samples.

Table 6

RESULTS OF TESTS ON POORLY GRADED FINE SAND--NO. 10--JANUARY 1964

Electromagnetic Vibrator No. 9, 0.1-cu-ft Measure

2-psi Single-piece Surcharge, Frequency = 3,600 cpm

Time of vibration, min	Rheostat setting, percent	Initial density, pcf	Moisture, final percent	Dry density, pcf	Av dry density (1) & (2) pcf
<u>1/</u> (1) 1	100	90.9	Ovendry	111.2	111.2
3				112.6	112.8
5				112.1	112.6
7				112.4	112.7
9				112.4	112.7
12				113.0	113.0
<u>1/</u> (2) 1	100	89.8	Ovendry	111.2	
3				112.9	
5				113.0	
7				113.0	
9				113.0	
12				113.0	
(1) 12	100	95.1	Ovendry	113.9	113.4
		min+5			
(2) 12	100	94.7	Ovendry	113.0	
		min+5			
(1) 12	100	100.0	Ovendry	113.4	113.3
		min+10			
(2) 12	100	100.0	Ovendry	113.2	
		min+10			
(1) 16	100	89.7	Ovendry	112.4	112.9
(2) 16	100	89.7	Ovendry	113.4	
(1) 16	90	89.5	Ovendry	113.3	113.3
(2) 16	90	89.9	Ovendry	113.3	
16	80	91.1	Ovendry	113.0	113.4
16	80	90.1	Ovendry	113.7	
16	70	89.5	Ovendry	113.6	113.9
16	70	90.2	Ovendry	114.2	
16	60	91.5	Ovendry	113.2	113.6
16	60	90.0	Ovendry	114.0	
16	50	91.5	Ovendry	114.0	114.2
16	50	89.8	Ovendry	114.3	
16	40	89.6	Ovendry	116.7	116.2
16	40	89.9	Ovendry	115.7	
16	30	91.6	Ovendry	115.0	115.7
16	30	89.8	Ovendry	116.4	
16	20	90.5	Ovendry	115.0	115.4
16	20	90.1	Ovendry	115.7	
20	100	-	15.0	114.2	114.4
20	100		14.4	114.5	
20	30	-	16.2	113.3	113.5
20	30		15.4	113.7	

1/Nos. (1) and (2) indicate duplicate samples.

Table 7

RESULTS OF TESTS ON POORLY GRADED FINE SAND--NO. 10--JANUARY 1964
Electromagnetic Vibrator No. 10, 0.1-cu-ft Measure
2-psi Single-piece Surcharge, Frequency = 3,600 cpm

Time of vibration, min	Rheostat setting, percent	Initial density, pcf	Moisture final percent	Dry density, pcf	Av dry density, pcf	
<u>1/</u> (1)	1	100	90.8	Ovendry	111.9	112.0
	3	100			112.7	113.2
	5	100			113.0	113.6
	7	100			113.4	113.8
	9	100			113.8	114.1
	12	100			113.1	113.8
<u>1/</u> (2)	1	100	90.3	Ovendry	112.1	
	3	100			113.8	
	5	100			114.1	
	7	100			114.2	
	9	100			114.4	
	12	100			114.5	
(1)	12	100	95.1	Ovendry	113.2	113.2
			min+5			
(2)	12	100	95.1	Ovendry	113.1	
			min+5			
(1)	12	100	98.9	Ovendry	113.7	113.6
			min+10			
(2)	12	100	98.9	Ovendry	113.6	
			min+10			
(1)	16	100	91.1	Ovendry	114.0	113.8
(2)	16	100	90.5	Ovendry	113.6	
(1)	16	90	90.8	Ovendry	112.9	113.1
(2)	16	90	90.6	Ovendry	113.3	
(1)	16	80	90.7	Ovendry	114.0	113.6
(2)	16	80	91.0	Ovendry	113.1	
(1)	16	70	91.7	Ovendry	113.7	113.6
(2)	16	70	90.4	Ovendry	113.5	
(1)	16	60	91.3	Ovendry	114.2	113.8
(2)	16	60	90.7	Ovendry	113.4	
(1)	16	50	91.5	Ovendry	112.9	113.0
(2)	16	50	91.2	Ovendry	113.1	
(1)	16	40	91.5	Ovendry	111.4	111.1
(2)	16	40	90.9	Ovendry	110.8	
(1)	16	30	91.5	Ovendry	102.7	106.4
(2)	16	30	90.9	Ovendry	110.0	
(1)	20	100		15.6	113.7	112.1
(2)	20	100		14.9	110.5	
(1)	20	90		15.3	113.2	
(1)	20	80		16.2	112.7	
(1)	20	70		16.2	111.5	

1/Nos. (1) and (2) indicate duplicate samples.

Table 8

RESULTS OF TESTS ON POORLY GRADED FINE SAND--NO. 10--JANUARY 1964
Eccentric-weight-type Vibrator No. 11, 0.1-cu-ft Measure
2-psi Single-piece Surcharge, Variable Frequency

Time of vibration, min	Rheostat setting, volts	Initial density, pcf	Moisture, final percent	Dry density, pcf	Av dry density, pcf (1) & (2)
<u>1/</u> (1) 0.5	120	89.7	Ovendry	106.6	
1				109.7	
3				110.5	
5				111.5	
7				112.0	
9				112.8	
12				112.6	112.2
<u>1/</u> (2) 2	120	89.3	Ovendry	109.2	
4				110.2	
6				110.9	
8				111.0	
10				111.4	
12				111.8	
(1) 12	120	95.1	Ovendry	114.0	114.2
		min+5			
(2) 12	120	95.1	Ovendry	114.4	
		min+5			
(1) 12	120	100.1	Ovendry	113.7	113.4
		min+10			
(2) 12	120	100.1	Ovendry	113.0	
		min+10			
(1) 16	120	89.9	Ovendry	112.6	113.4
(2) 16	120	91.0	Ovendry	114.1	
(1) 16	110	90.9	Ovendry	113.8	113.2
(2) 16	110	90.6	Ovendry	112.5	
(1) 16	100	91.5	Ovendry	112.9	113.2
(2) 16	100	90.9	Ovendry	113.6	
(1) 16	90	90.5	Ovendry	113.3	113.6
(2) 16	90	91.0	Ovendry	113.9	
(1) 16	80	90.7	Ovendry	113.3	113.3
(2) 16	80	90.6	Ovendry	113.3	
(1) 16	70	90.9	Ovendry	109.6	110.1
(2) 16	70	90.5	Ovendry	110.6	
(1) 20	120	-	16.3	111.2	108.2
(2) 20	120	-	14.7	105.3	

1/Nos. (1) and (2) indicate duplicate samples.

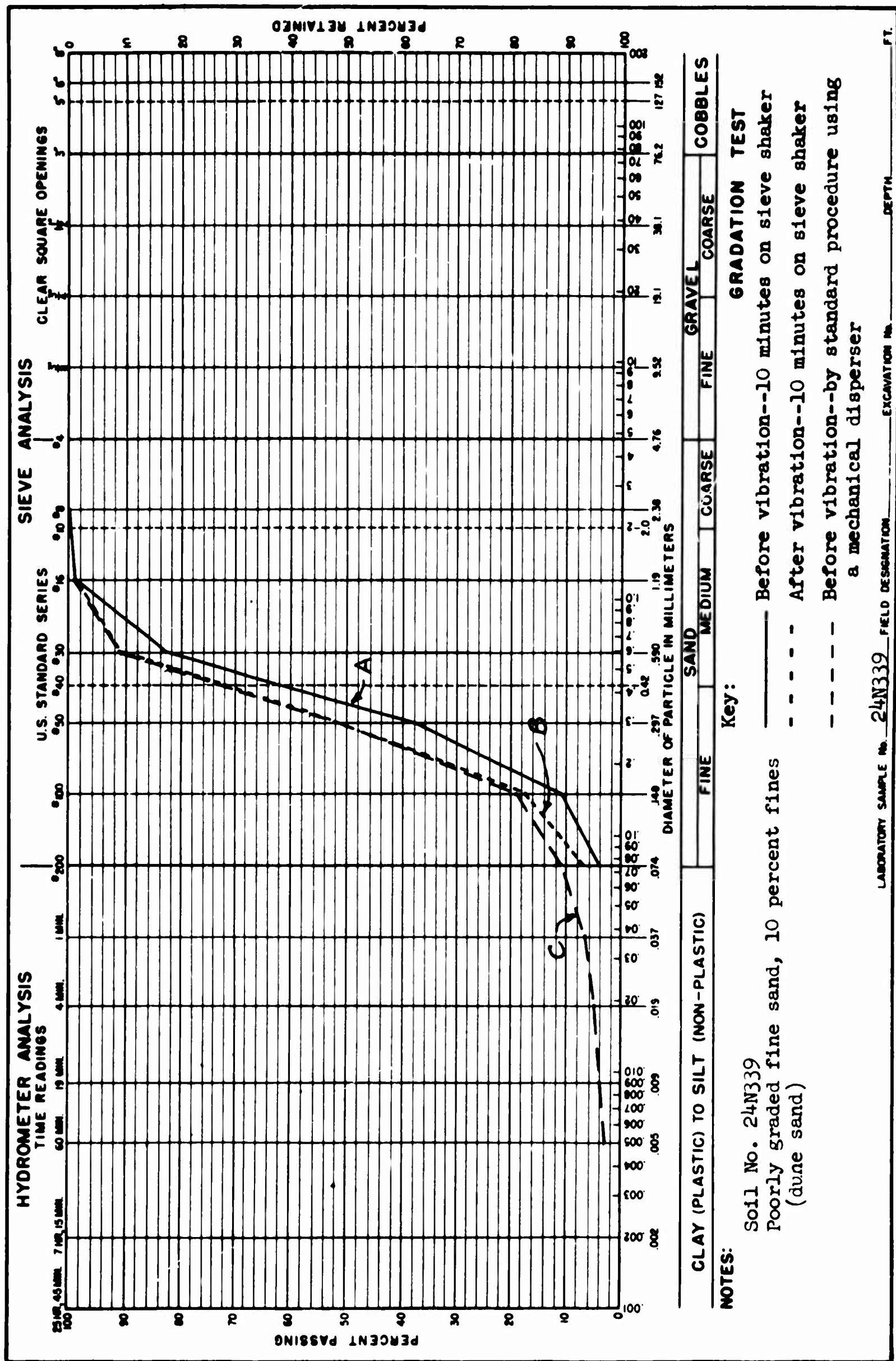


FIGURE NO. 1

HYDROMETER ANALYSIS

TIME READINGS

25 MIN. 40 MIN. 7 MIN. 15 MIN.

60 MIN. 120 MIN.

4 MIN.

1 MIN.

SIEVE ANALYSIS

U.S. STANDARD SERIES

0.075 0.15 0.3 0.6 1.18 2.0 4.75 7.5 14.8 25 47.5 75 106 200 425 850 1060 2000 4250 8500 17500 35000 70000 140000 280000 560000 1120000 2240000 4480000 8960000 17920000 35840000 71680000 143360000 286720000 573440000 1146880000 2293760000 4587520000 9175040000 18350080000 36700160000 73400320000 146800640000 293601280000 587202560000 1174405120000 2348810240000 4697620480000 9395240960000 18790481920000 37580963840000 75161927680000 150323855360000 300647710720000 601295421440000 1202590842880000 2405181685760000 4810363371520000 9620726743040000 19241453486080000 38482906972160000 76965813944320000 153931627888640000 307863255777280000 615726511554560000 1231453023109120000 2462906046218240000 4925812092436480000 9851624184872960000 19703248369745920000 39406496739491840000 78812993478983680000 157625986957967360000 315251973915934720000 630503947831869440000 1261007895663738880000 2522015791327477760000 5044031582654955520000 10088063165309911040000 20176126330619822080000 40352252661239644160000 80704505322479288320000 161409010644958576640000 322818021289917153280000 645636042579834306560000 1291272085159668613120000 2582544170319337226240000 5165088340638674452480000 10330176681277348904960000 20660353362554697809920000 41320706725109395619840000 82641413450218791239680000 165282826900437582479360000 330565653800875164958720000 661131307601750329917440000 1322262615203500659834880000 2644525230407001319669760000 5289050460814002639339520000 10578100921628005278679040000 21156201843256010557358080000 42312403686512021114716160000 84624807373024042229432320000 169249614746048084458864640000 338499229492096168917729280000 676998458984192337835458560000 1353996917968384675670917120000 2707993835936769351341834240000 5415987671873538702683668480000 10831975343747077405367336960000 21663950687494154810734673920000 43327901374988309621469347840000 86655802749976619242938695680000 173311605499953238485877391360000 346623210999906476971754782720000 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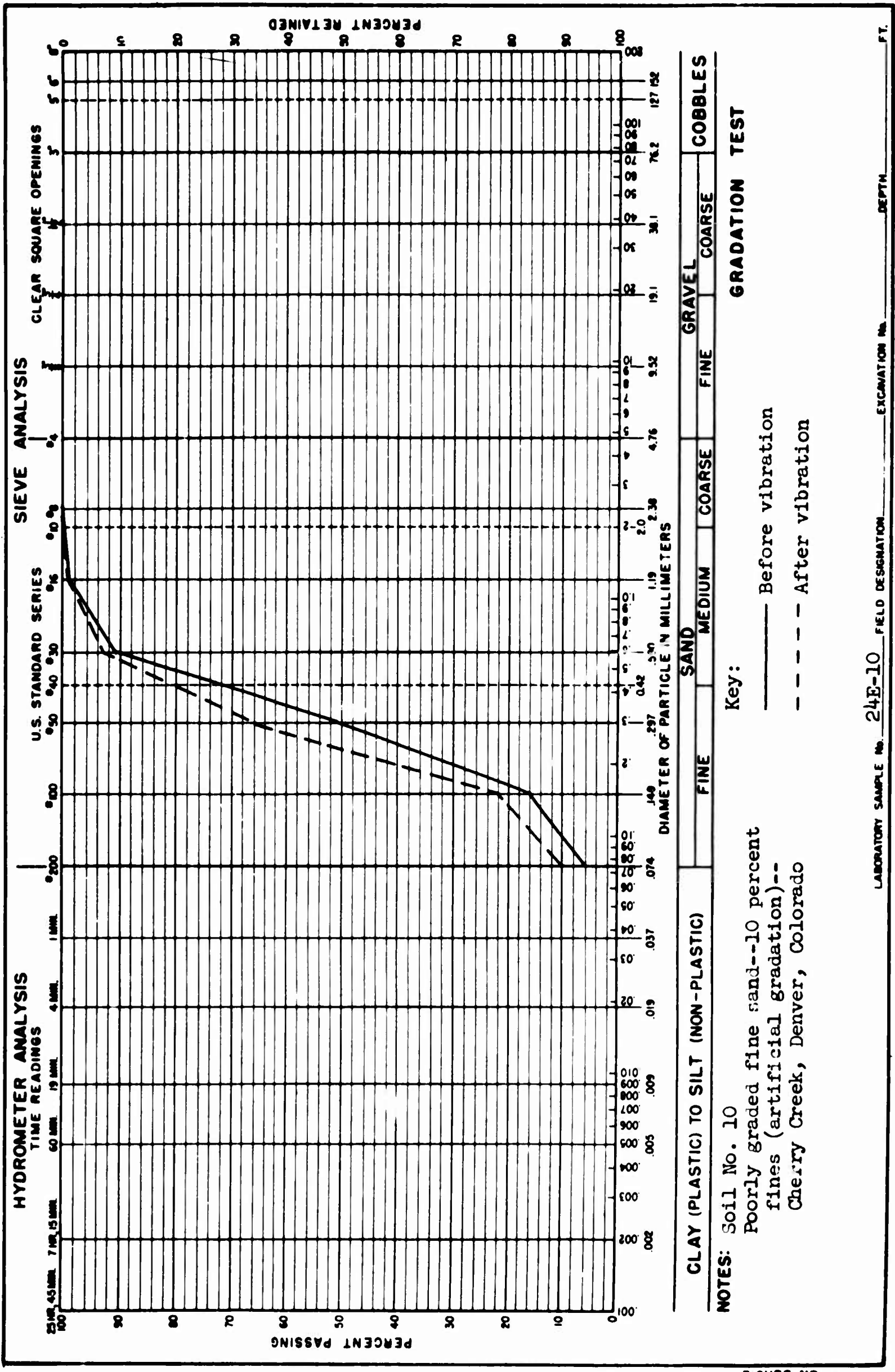
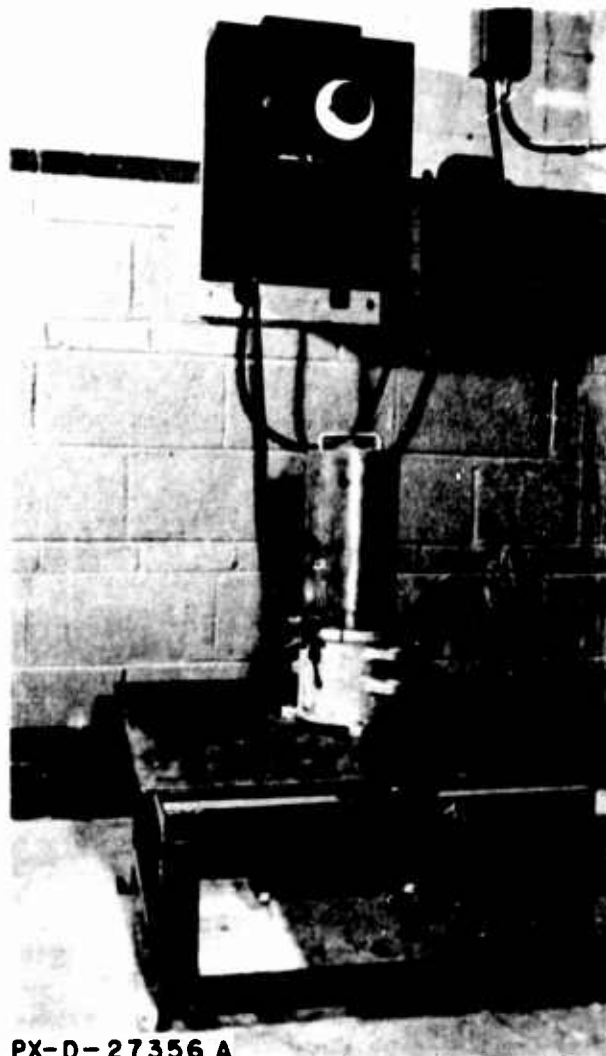


FIGURE NO. 3



PX-D-27358 A

Pouring minimum density in 0.1-cu-ft measure.



PX-D-27356 A

Large electromagnetic table-type vibrator (No. 9)
with 0.1-cu-ft measure, guide sleeve and 2-psi
surcharge.



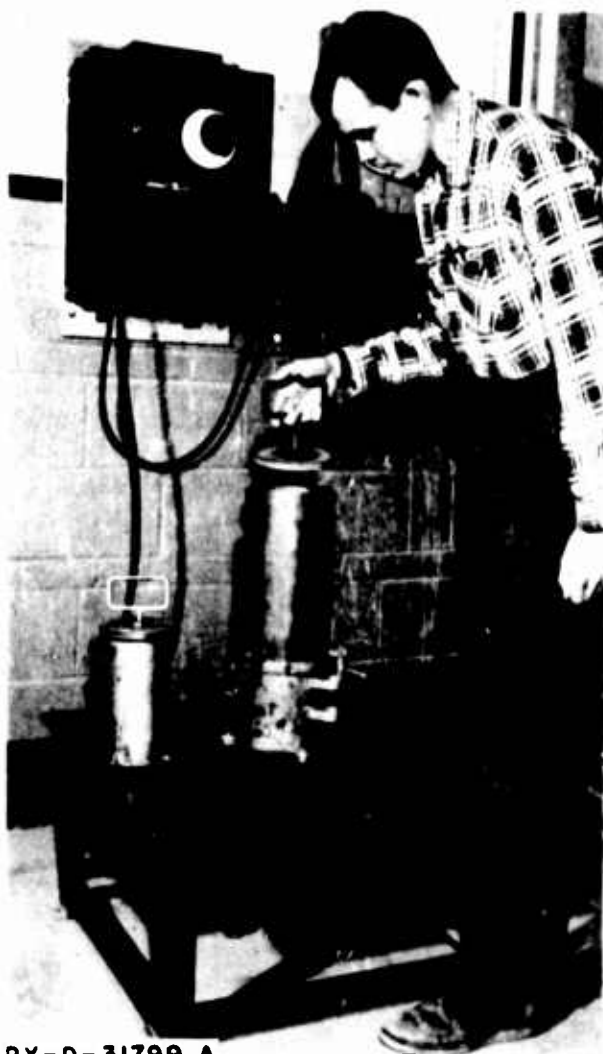
PX-D-43294 NA

Small electromagnetic table-type vibrator (No. 10)
with 0.1-cu-ft measure, guide sleeve and 2-psi
surcharge.



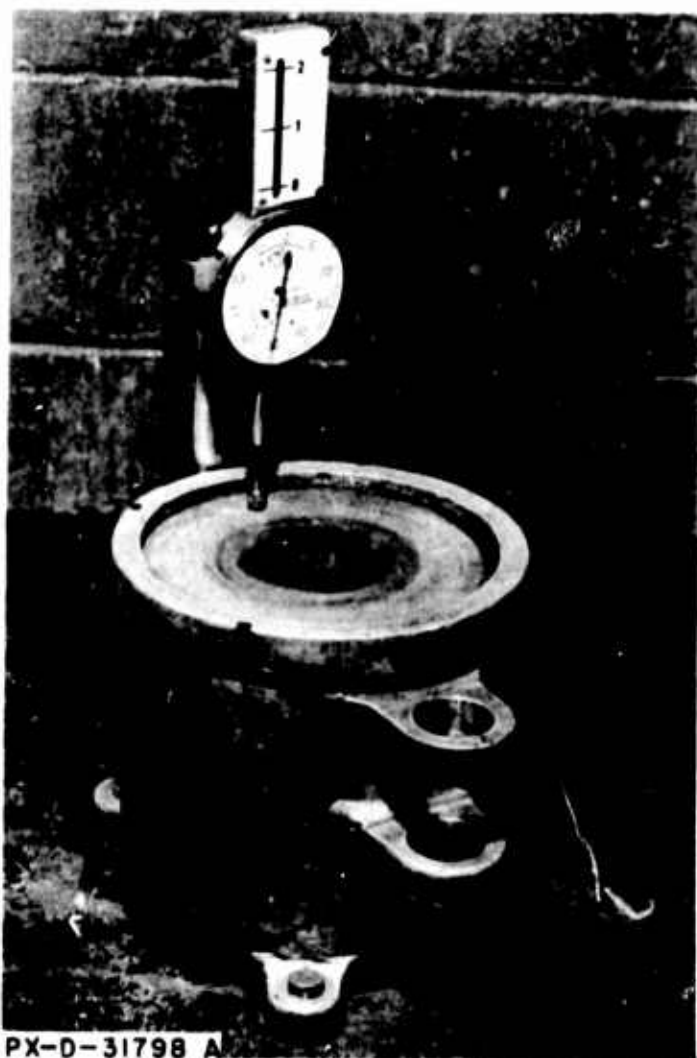
PX-D-48508 NA

Eccentric-weight table-type vibrator (No. 11).
Dismounted to show vibrator attached to shop-
made table.



PX-D-31799 A

Placing surcharge baseplate on soil specimen.
Note solid 2-psi surcharge weight on vibratory
table.



Making final dial reading on 0.1-cu-ft measure.

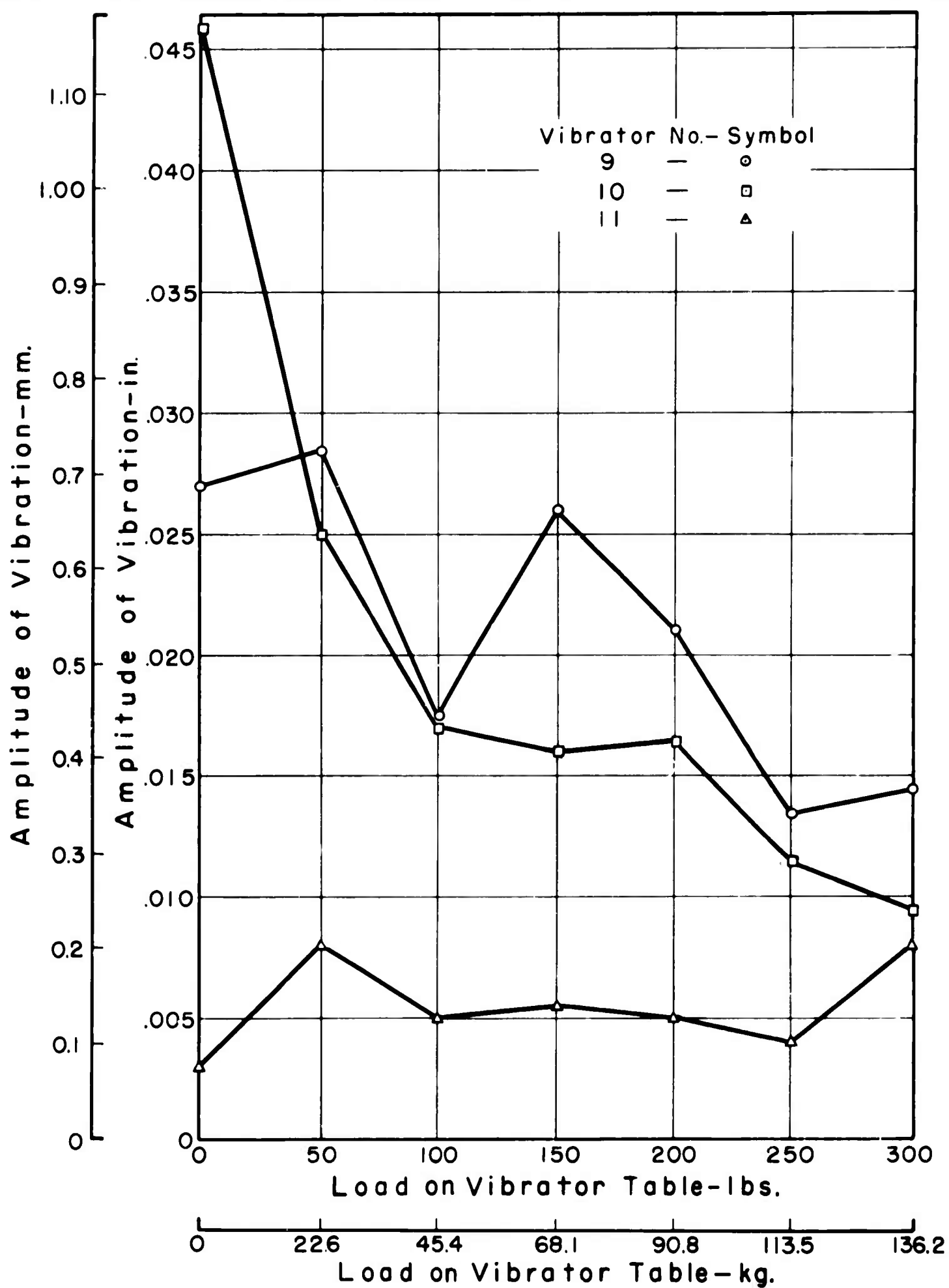


Fig.10 Amplitude vs. Load on Vibrator at Maximum Rheostat Setting

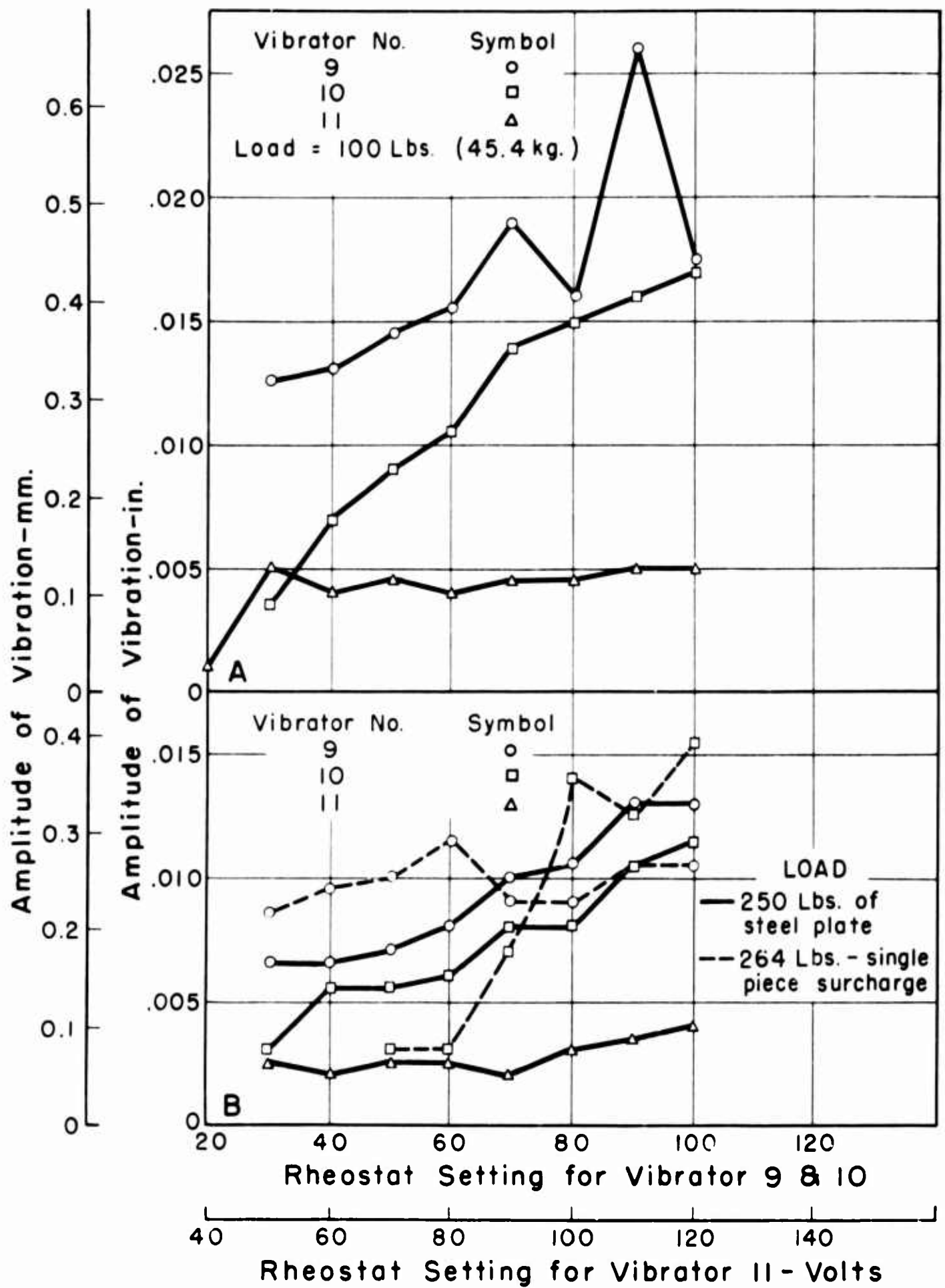


Fig. II Amplitude of Vibration vs. Rheostat Setting

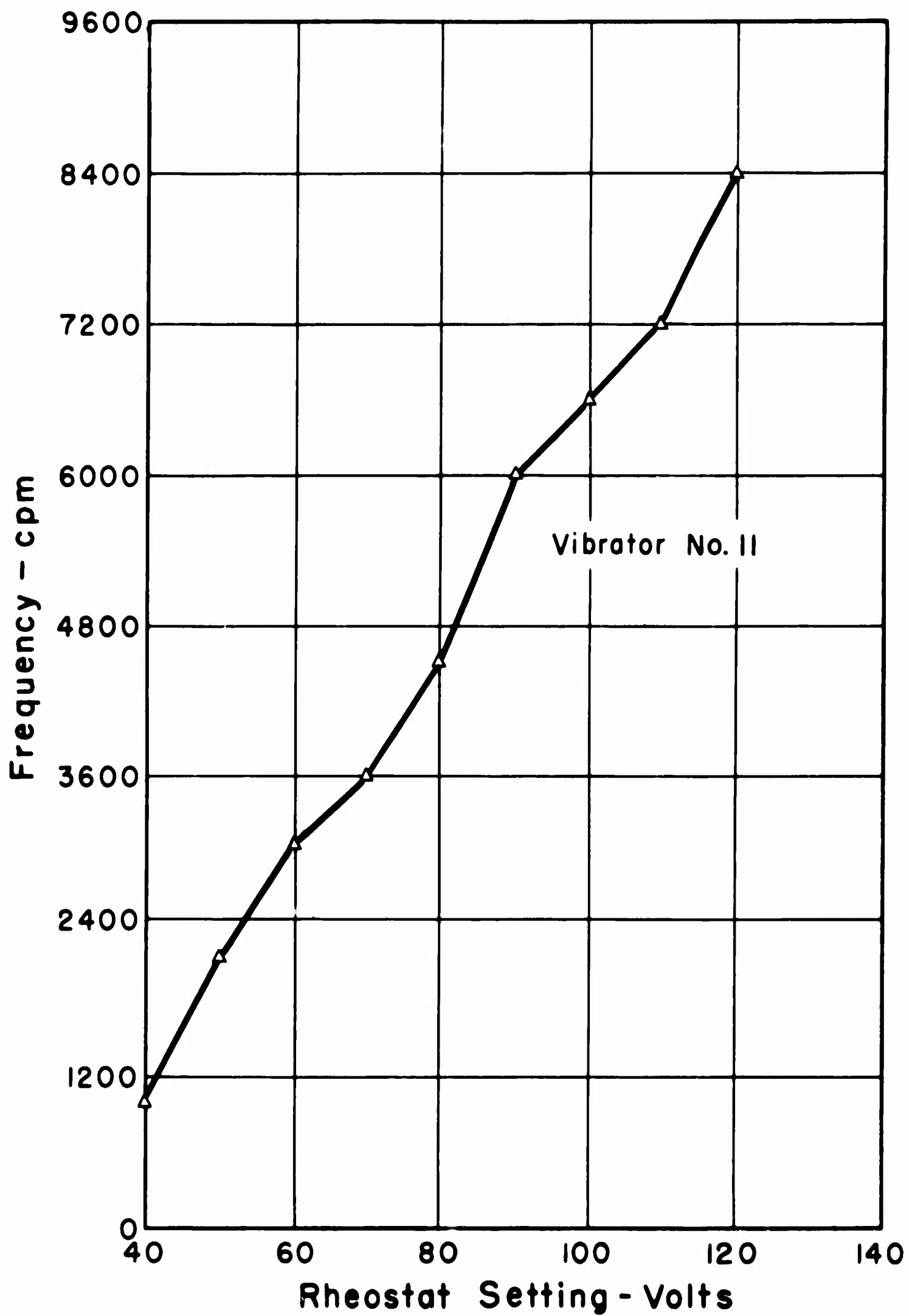


Fig.12 Frequency vs. Rheostat Setting for Vibrator No. II

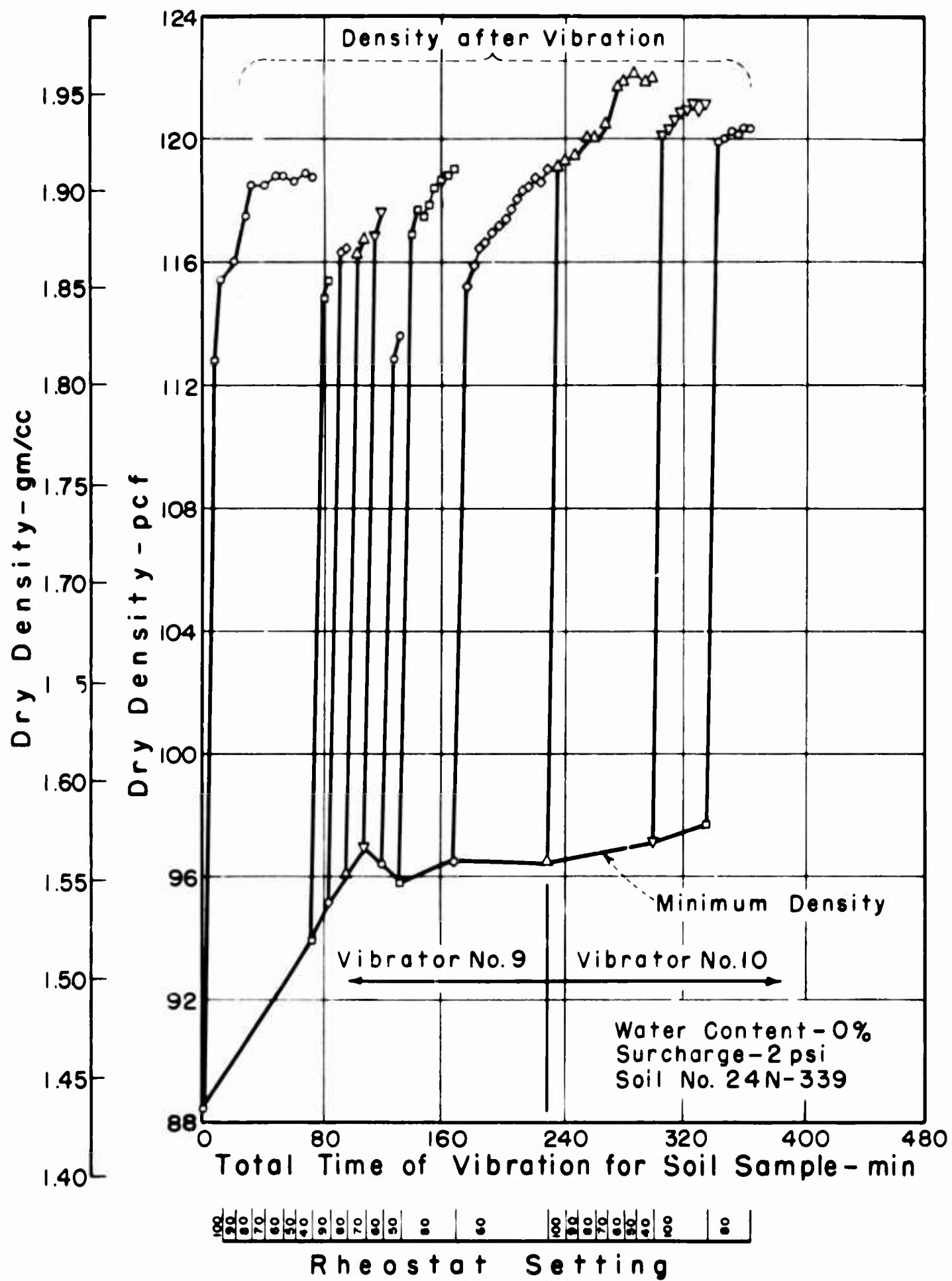


Fig.13 Dry Density vs. Time of Vibration and Rheostat Setting

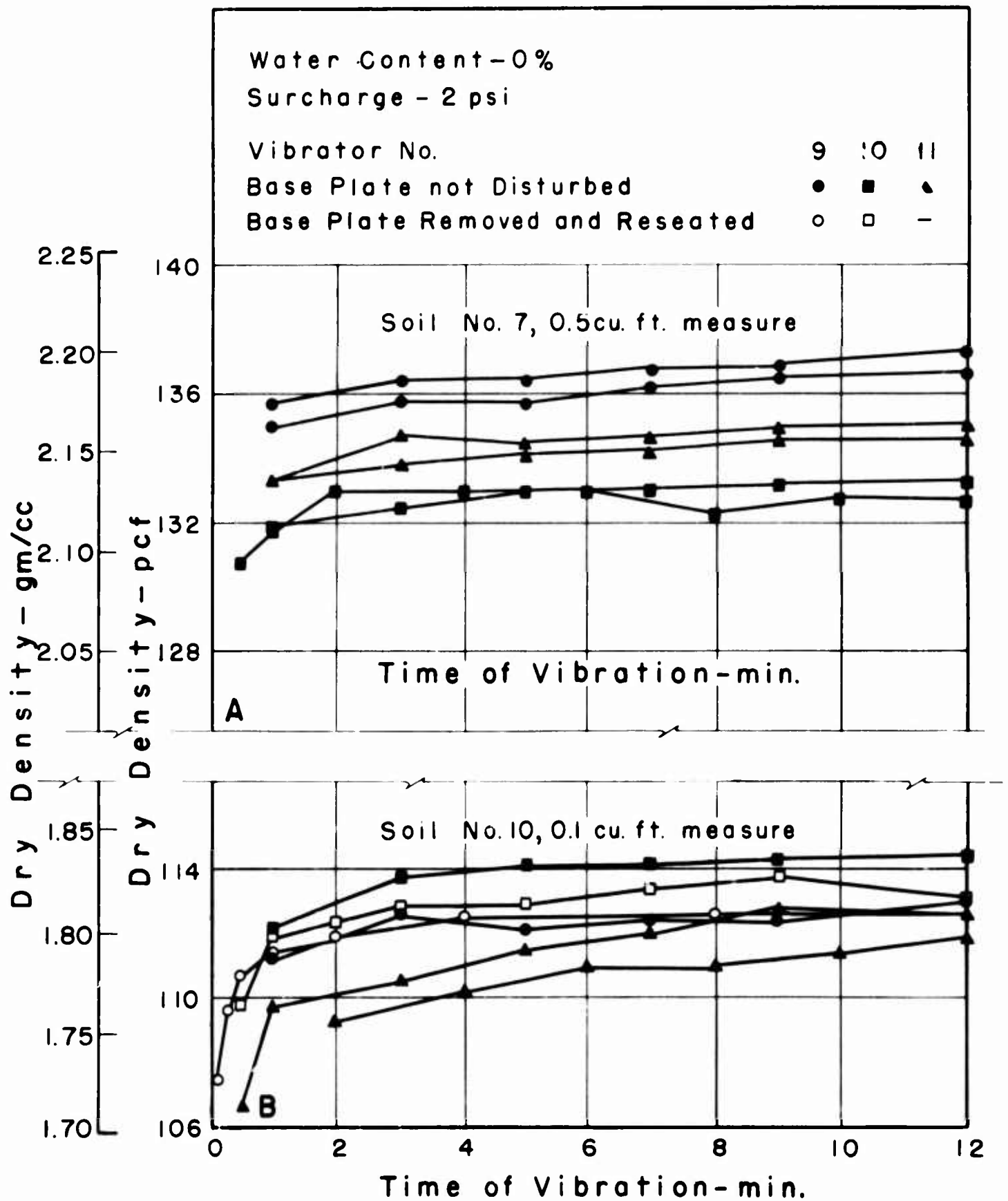


Fig. 14 Dry Density vs Time of Vibration

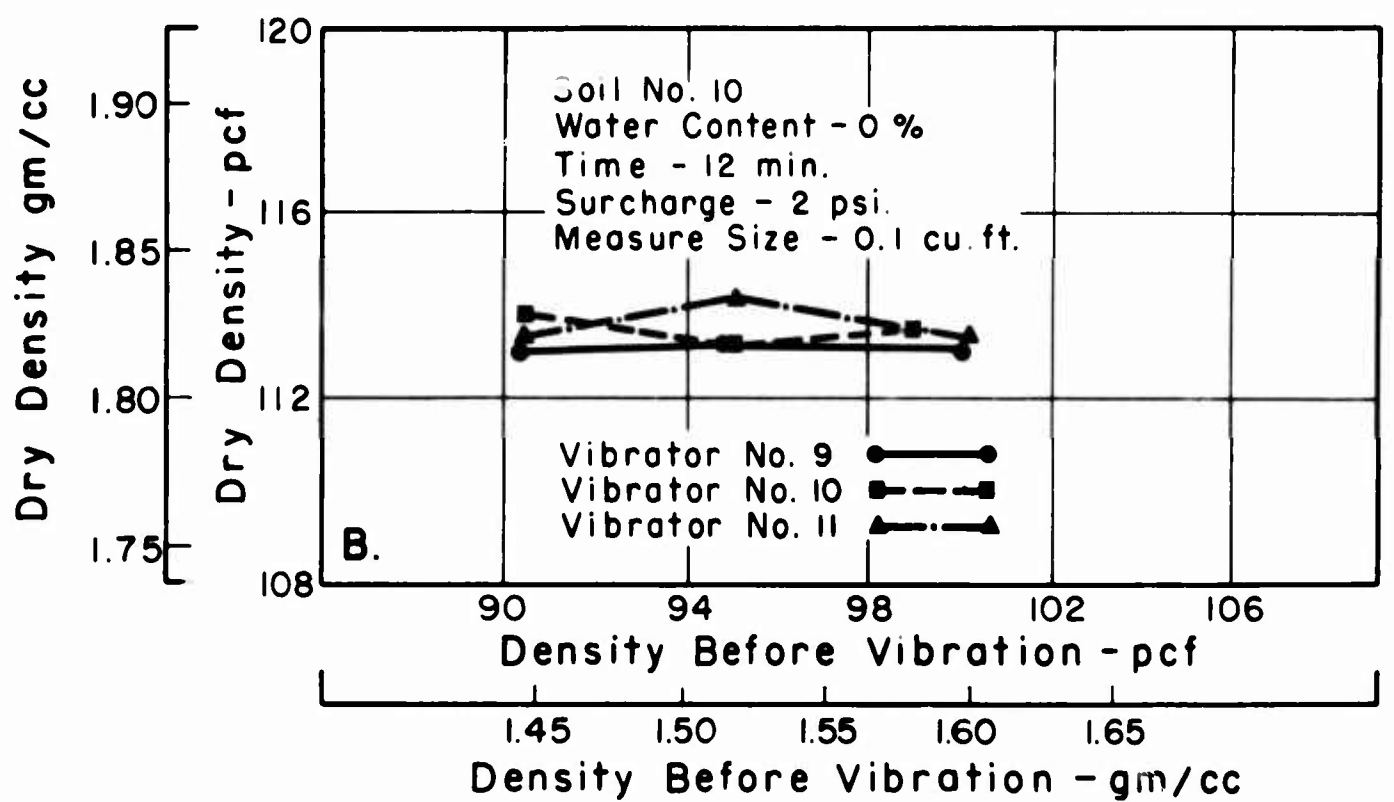
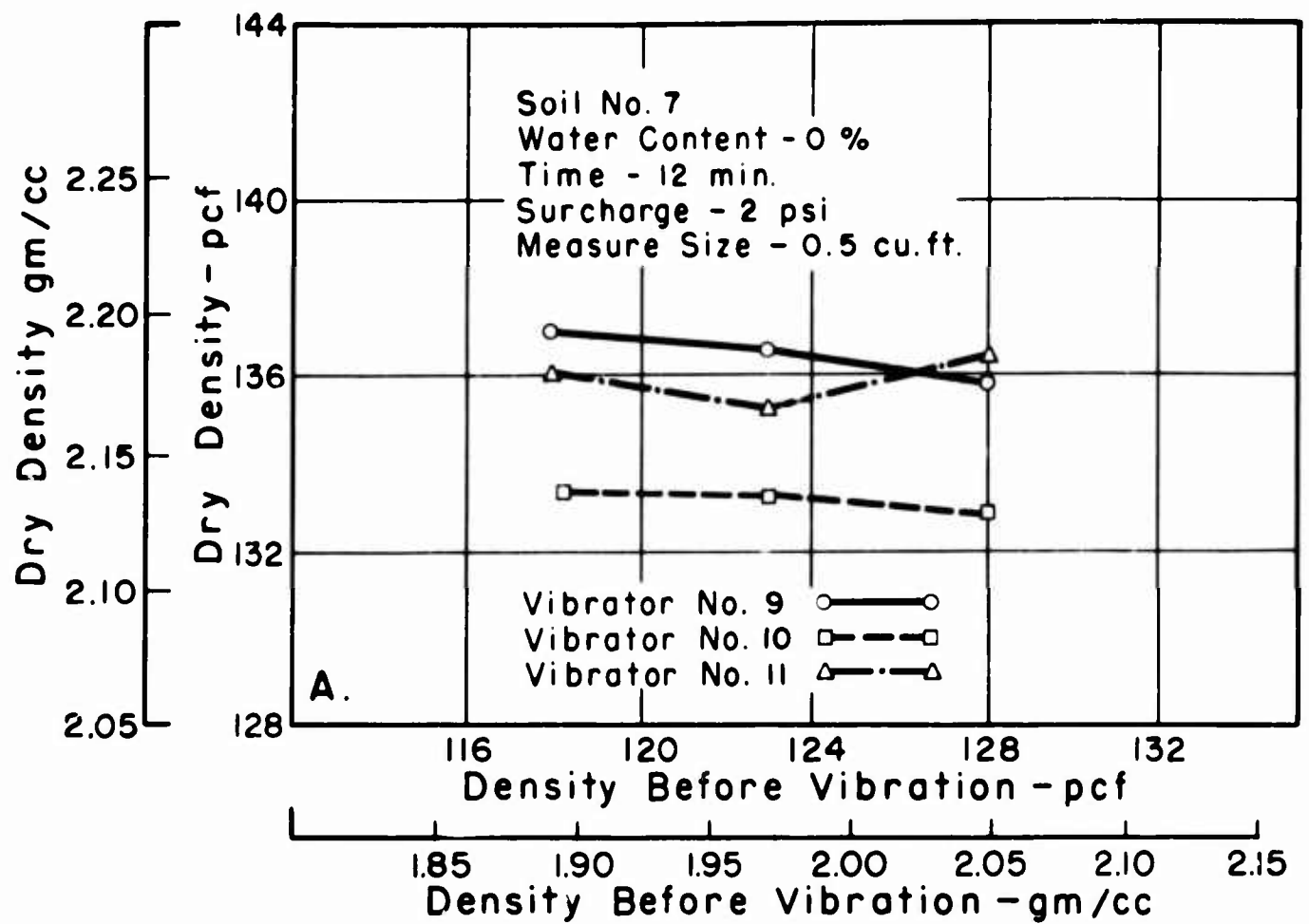


Fig. 15 Dry Density Vs. Density Before Vibration

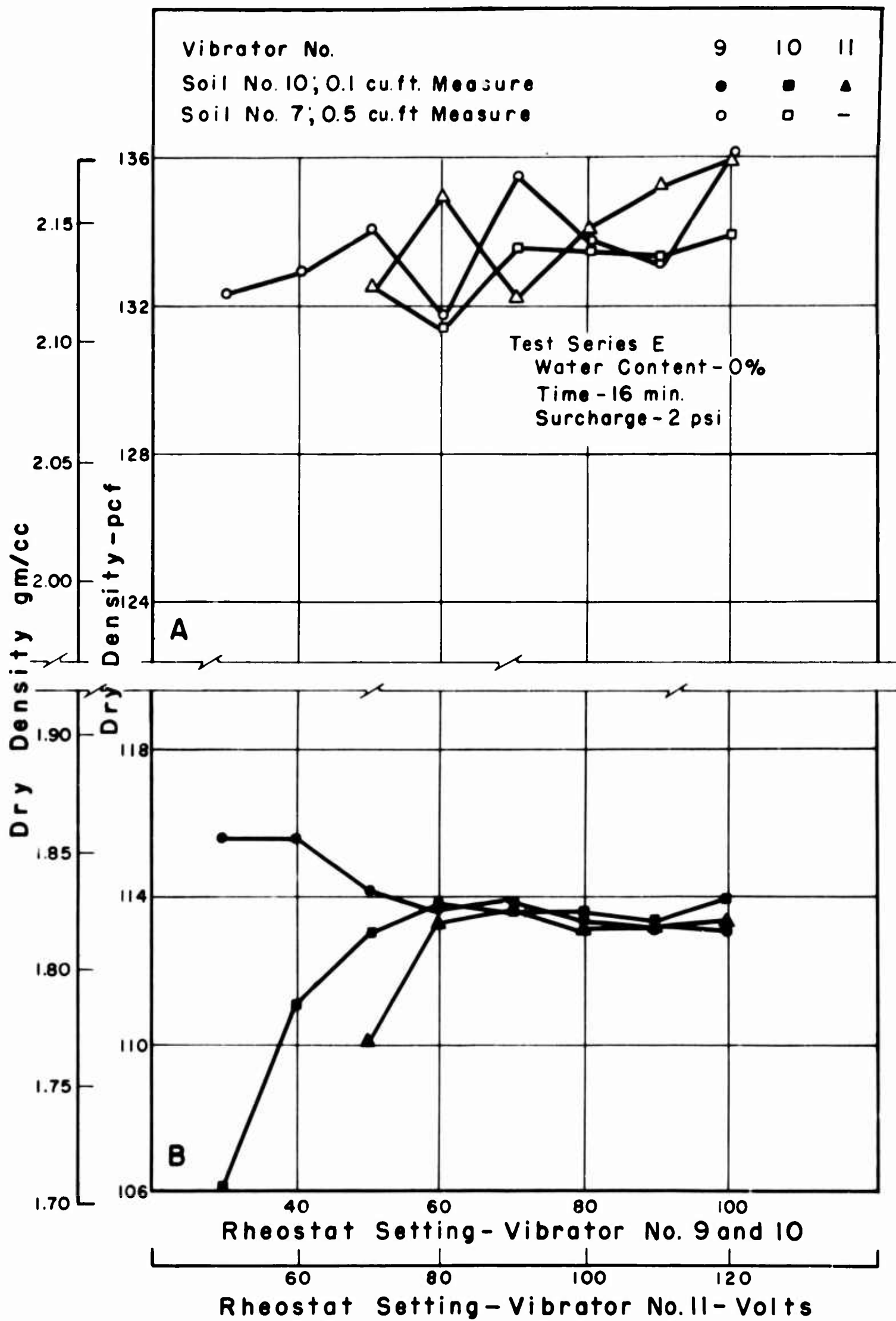


Fig.16 Dry Density vs Rheostat Setting

APPENDIX A

Retesting of Soils to Compare Results Obtained with New Test
Procedure and Equipment with Previous Results

PURPOSE

Investigations of methods to determine the maximum density of cohesionless soils have been carried on in the Soils Engineering Branch since about 1954. A number of different types of vibrators and a wide variety of soils have been tested. The tests reported in this appendix were run to compare present methods with some of the methods used in the past.

TEST PROCEDURE

A number of tests were run according to the test procedure prescribed in Designation E-12B1/ using Vibrators No. 9, 10, and 11 on Soils No. 1, 2, 3, 4, 6, 7, and 9 which had been used in previous investigations. 2.3.4/ Standard gradation tests (Designation E-6) 1/ were run on each soil and compared with the results of standard gradation tests which were run on the soils before they were vibrated the first time.

TEST RESULTS

The maximum densities obtained during this retesting of Soils No. 1, 2, 3, 4, 6, 7, and 9 are compared with the maximum densities obtained in previous tests in Table A-1. The results of gradation tests on these soils before and after vibration are presented in Figures A-1 through A-7. The gradation before vibration was determined when the material was first received in the laboratory in the year 1957 while the gradation after vibration was determined in 1964. Between the before and after gradations the soils had been subject to various types of vibration for a total of about 6 hours.

DISCUSSION OF TEST RESULTS

Major changes in gradation occurred in Soils No. 1, 2, 3, and 4 between the time the material was received and tests in 1964. Soils No. 1, 2, and 4 became coarser while Soil No. 3 became finer. Two mechanisms work to change soil gradation: (1) a breakdown of particles by mechanical action, and (2) a loss of the finer material during storage and handling and by migration of fines from the top of the measure during vibration testing. Minor changes in gradation were also observed for Soils No. 6 and 7, but no appreciable change was noted in the gradation of Soil No. 9.

Since the effect of gradation changes on the soil density obtained in a vibration test is unknown, no conclusions can be drawn as to the efficiency of the present procedure compared to the procedures used in earlier investigations.

CONCLUSION

The meaning of the results presented in this Appendix is not clear from the available data, but are presented here for possible use in future investigations.

Table A-I

AVERAGE DENSITIES OBTAINED DURING
RELATIVE DENSITY RESEARCH

Soil type	: Av of 3 : tests	: Av of 3 : tests	:	:	:	:	:	:	:
	: Av max : density, : pcf	: Av min : density, : pcf	: Vibrator : No.	: Mold : size, : cu ft	: Av of 3 : tests : moisture : percent	: Amount : PSI	: Surcharge : G = Guided : H = Hand held	:	:
1	111.6	91.5	1	0.1	0	0.53	H		
1	110.5	<u>1/</u> 93.4	9	0.1	0	2.0	G		
1	109.8	<u>1/</u> 93.4	10	0.1	0	2.0	G		
2	123.5	102.6	1	0.1	0	1.14	H		
2	119.2	<u>1/</u> 101.4	9	0.1	0	2.0	G		
2	120.1	<u>1/</u> 101.4	10	0.1	0	2.0	G		
2	121.5	<u>1/</u> 101.4	11	0.1	0	2.0	G		
3	121.6	98.4	1	0.1	0	1.14	H		
3	116.1	<u>1/</u> 101.1	9	0.1	0	2.0	G		
3	120.1	<u>1/</u> 101.1	10	0.1	0	2.0	G		
4	140.8	121.6	1	0.5	0	0.17	H		
4	<u>1/</u> 144.8		7	0.5	<u>1/</u> 4.5	2.0	G		
4	147.3	<u>1/</u> 119.3	9	0.1	4.2	2.0	G		
4	146.5	<u>1/</u> 119.3	10	0.1	4.4	2.0	G		
6	132.4	101.3	1	0.1	0	1.15	H		
6	<u>1/</u> 144.0		7	0.1	6.0	2.0	G		
6	141.7	<u>1/</u> 109.3	9	0.1	6.8	2.0	G		
6	135.2	<u>1/</u> 109.3	10	0.1	8.7	2.0	G		
7	<u>1/</u> 147.5		7	0.5	7.5	2.0	G		
7	136.8	120.1	9	0.5	6.7	2.0	G		
7	133.6	118.9	10	0.5	7.3	2.0	G		
9	<u>1/</u> 141.5		7	0.5	4.9	3.0	G		
9	139.4	118.7	9	0.5	5.7	2.0	G		
9	133.8	<u>1/</u> 120.0	10	0.5	6.5	2.0	G		

1/ Only one test.

HYDROMETER ANALYSIS

TIME READINGS

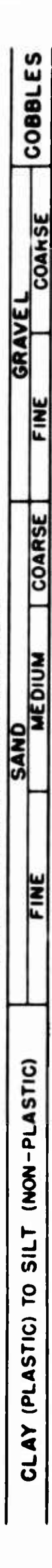
25 HR. 45 MIN. 7 HR. 15 MIN. 60 MIN. 15 MIN. 1 MIN. 4 MIN.

SIEVE ANALYSIS

U.S. STANDARD SERIES

0.075 0.15 0.3 0.6 1.18 2.0 4.75 9.5 19.0 37.5 75 150 300 600 1200 2500 5000 10000 20000 40000 80000 160000 320000 640000 1280000 2560000 5120000 10240000 20480000 40960000 81920000 163840000 327680000 655360000 1310720000 2621440000 5242880000 10485760000 20971520000 41943040000 83886080000 167772160000 335544320000 671088640000 1342177280000 2684354560000 5368709120000 10737418240000 21474836480000 42949672960000 85899345920000 171798691840000 343597383680000 687194767360000 1374389534720000 2748779069440000 5497558138880000 10995116277760000 21990232555520000 43980465111040000 87960930222080000 175921860444160000 351843720888320000 703687441776640000 1407374883553280000 2814749767106560000 5629499534213120000 11258999068426240000 22517998136852480000 45035996273704960000 90071992547409920000 180143985094819840000 360287970189639680000 720575940379279360000 1441151880758558720000 2882303761517117440000 5764607523034234880000 11529215046068469760000 23058430092136939520000 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53169119831396634916152282411213783040000 106338239662793269832304564822427566080000 212676479325586539664609129644855132160000 425352958651173079329218259289710264320000 850705917302346158658436518579420528640000 1701411834604692317316873037158841057280000 3402823669209384634633746074317682114560000 6805647338418769269267492148635364229120000 13611294676837538538534984297270728458240000 27222589353675077077069968594541456916480000 54445178707350154154139937189082913832960000 108890357414700308308279874378165827665920000 217780714829400616616559748756331655331840000 435561429658801233233119497512663310663680000 871122859317602466466238995025326621327360000 1742245718635204932932477990050653242654720000 3484491437270409865864955980101306485309440000 6968982874540819731729911960202612970618880000 13937965749081639463459823920405225941237760000 27875931498163278926919647840810451882475520000 55751862996326557853839295681620903764951040000 111503725992653115707678591363241807529902080000 223007451985306231415357182726483615059804160000 446014903970612462830714365452967230119608320000 892029807941224925661428730905934460239216640000 1784059615882449851322857461811868920478433280000 3568119231764899702645714923623737840956866560000 7136238463529799405291429847247475681913733120000 14272476927059598810582859694494951363827466240000 28544953854119197621165719388989902727654932480000 57089907708238395242331438777979805455309864960000 114179815416476790484662877555959610910619729920000 228359630832953580969325755111919221821239459840000 456719261665907161938651510223838443642478919680000 913438523331814323877303020447676887284957839360000 1826877046663628647754606040895353774569915678720000 3653754093327257295509212081790707549139831357440000 7307508186654514591018424163581415098279662714880000 14615016373309029182036848327162830196559325429760000 29230032746618058364073696654325660393118650859520000 58460065493236116728147393308651320786237301719040000 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15324955408658888583583470271503091836187391221836021760000 30649910817317777167166940543006183672374782443672043520000 61299821634635554334333881086012367344749564887344087040000 122599643269271108668667762172024734689499129774688174080000 245199286538542217337335524344049469378998259549376348160000 490398573077084434674671048688098938757996519098752696320000 980797146154168869349342097376197877515993038197505392640000 1961594292308337738698684194752395755031986076395010785280000 3923188584616675477397368389504791510063972152790021570560000 7846377169233350954794736779009583020127944305580043141120000 15692754338466701909589473558019166040255888611160086282240000 31385508676933403819178947116038332080511777222320172564480000 62771017353866807638357894232076664161023554444640345128960000 125542034707733615276715788464153328322047108889280690257920000 251084069415467230553431576928306656644094217778561380515840000 502168138830934461106863153856613313288188435557122761031680000 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4417117661945960823958243751857296289568709742189047395304015503231549440000 8834235323891921647916487503714592579137419484378094790608031006463098880000 17668470647783843295832975007429185158274838968756189581216062012926197760000 35336941295567686591665950014858370316549677937512379162432124025852395520000 70673882591135373183331900029716740633099355875024758324864248051704791040000 141347765182270746366663800059433481266198711750049516649728496103409582080000 282695530364541492733327600118866962532397423500099033299456992206819164160000 565391060729082985466655200237733925064794847000198066598913984413638328320000 1130782121458165970933310400475467850129589694000396133197827968827276656640000 2261564242916331941866620800950935700259179388000792266395655937654553313280000 4523128485832663883733241601901871400518358776001584532791311875309106626560000 9046256971665327767466483203803742801036717552003169065582623750618213253120000 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74106937111882365071085430405560261026092790186009960985252853765064402969559040000 148213874223764730142170860811120522052185580372019921970505707530128805939118080000 296427748447529460284341721622241044104371160744039843941011415060257611878236160000 59285549689505892056868344324448208820874232148807968788202283012051522375647232

1



----- After vibration

1.

HYDROMETER ANALYSIS TIME READINGS

23.48, 45 MIN. 7.48, 15 MIN.

60 MIN. 15 MIN.

4 MIN.

1 MIN.

SIEVE ANALYSIS

U.S. STANDARD SERIES

CLEAR SQUARE OPENINGS

PERCENT RETAINED

PERCENT PASSING

DIAMETER OF PARTICLE IN MILLIMETERS

CLAY (PLASTIC) TO SILT (NON-PLASTIC)

SAND

MEDIUM

FINE

GRAVEL

COARSE

COBBLES

NOTES: Soil No. 7

Poorly graded sand and gravel--3-inch maximum size, no fines (artificial gradation), South Platte River, Denver, Colorado

Key:

GRADATION TEST

— Before vibration

- - - After vibration

LABORATORY SAMPLE NO. 24E-7 FIELD DESIGNATION

EXCAVATION NO.

DEPTH

FIGURE NO. A-6

APPENDIX B

Tests Using a Sieve Shaker to Obtain the Maximum Density of Cohesionless Soils

PURPOSE

The sieve shaker shown in Figure B-1 is used in many laboratories to determine the gradation of coarse-grained soils. The frequency of "shaking" is about 600 cpm and the amplitude is approximately 0.5 inches. These values of amplitude and frequency differ greatly from those of the vibrators used in investigations of the maximum density of cohesionless soils. A limited number of tests were run to compare the efficiency of the sieve shaker with vibrators previously used.

TEST PROCEDURE

A steelplate was fabricated to fit one of the sieve slots. The measure was attached to the steelplate as shown in Figure B-2. The measure was filled with soil and the steelplate and measure were tightened in the shaker as shown in Figure B-3. Other aspects of the test procedure were the same as described in the body of this report.

TEST RESULTS

Duplicate tests were run on two soils: a poorly graded sand and gravel (Soil No. 7) and a poorly graded fine sand (Soil No. 10). The densities obtained using the sieve shaker are compared with the densities obtained with the large electromagnetic vibrator (No. 9) in Tables B-1 and B-2. The shaker performed well under the load of approximately 100 pounds required for tests on Soil No. 10; but under the load of approximately 250 pounds required for tests on Soil No. 7 the motor overheated and stopped after running about 10 minutes.

DISCUSSION AND CONCLUSION

From the comparison in Table B-1, it is obvious that the sieve shaker cannot be used to obtain the maximum density of Soil No. 7, since the density obtained by the shaker is approximately 10 pounds less than the density obtained by Vibrator No. 9. Also, the motor overheated under the load required for the 0.5-cubic-foot measure.

The sieve shaker appears to give higher maximum densities for Soil No. 10 than were obtained by other vibrators, and the sieve shaker appears to operate very well under the load required for the 0.1-cubic-foot measure.

From the limited number of tests available, it appears that the sieve shaker gives slightly higher maximum densities for some soils, but much lower maximum densities for other soils.

Table B-1

COMPARISON OF DENSITIES OBTAINED BY SIEVE SHAKER
WITH DENSITIES OBTAINED BY VIBRATOR NO. 9 ON A
POORLY GRADED GRAVEL (SOIL NO. 7)

Ovendry

Sieve shaker		:	Vibrator No. 9	
Density, pcf	Time of vibration, min	:	Density, pcf	Time of vibration, min
115.7	0 (minimum)	:	118.0	0 (minimum)
123.9	2	:	135.7	1
124.5	4	:	136.4	3
125.8	8	:	136.5	5
125.8	12	:	136.8	7
		:	136.9	9
		:	137.3	12
116.8	0 (minimum)	:	117.8	0 (minimum)
126.7	4	:	135.0	1
123.3	8	:	135.8	3
123.4	12	:	135.7	5
124.0	16	:	136.3	7
		:		9
		:		12

Table B-2

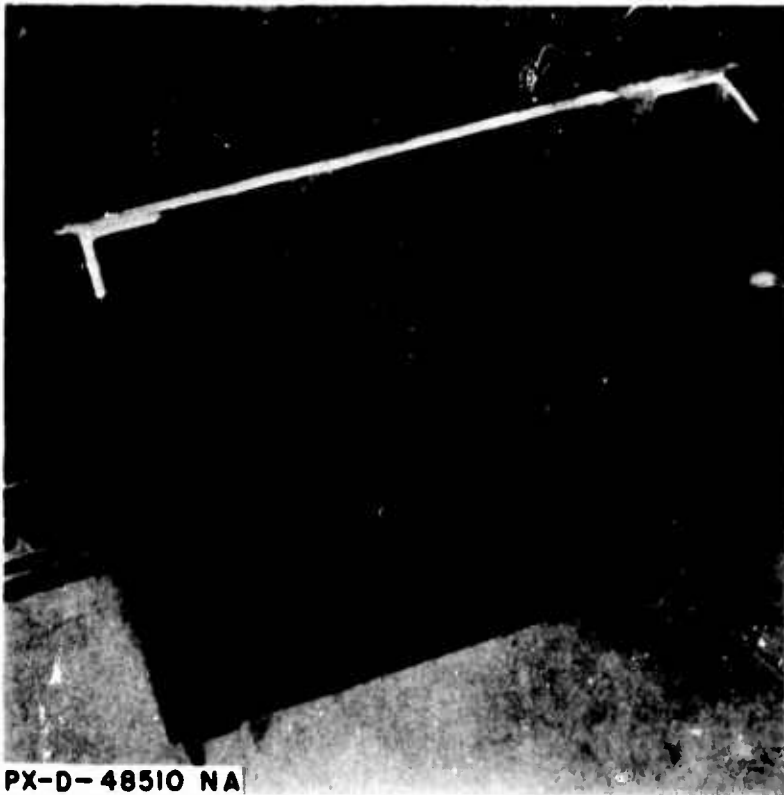
COMPARISON OF DENSITIES OBTAINED BY SIEVE SHAKER
WITH DENSITIES OBTAINED BY VIBRATOR NO. 9 ON A
POORLY GRADED GRAVEL (SOIL NO. 10)

Ovendry					
Sieve shaker			Vibrator No. 9		
Density, pcf	Time of vibration, min	:	Density, pcf	Time of vibration, min	:
88.4	0	:	90.9	0	:
	(minimum)	:		(minimum)	:
108.2	2	:	111.2	1	:
109.2	4	:	112.6	3	:
113.1	8	:	112.1	5	:
116.1	16	:	112.4	7	:
		:	112.4	9	:
		:	113.0	12	:
110.7	4	:	89.8	0	:
		:		(minimum)	:
111.9	8	:	111.2	1	:
114.6	12	:	112.9	3	:
115.1	16	:	113.0	5	:
		:	113.0	7	:
		:	113.0	9	:
		:	113.0	12	:
Initially saturated					
107.5	4	:	114.2	4	:
109.5	8	:	114.0	8	:
111.6	12	:	114.1	12	:
113.7	16	:	114.1	16	:
		:	114.2	20	:
111.7	4	:	114.6	4	:
113.1	8	:	114.5	8	:
114.2	12	:	114.7	12	:
115.2	16	:	114.7	16	:
116.0	20	:	114.5	20	:
		:			:

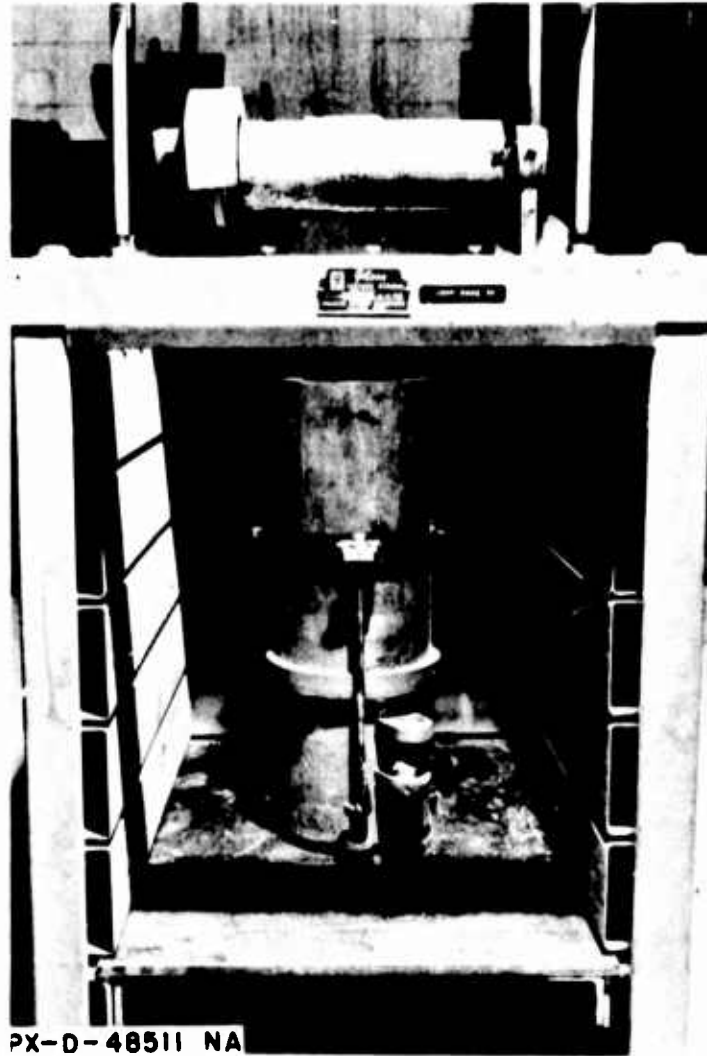


PX-D-48509 NA

Sieve shaker for determining the gradation of coarse-grained soils.



Steelplate adapter for sieve shaker.



Sieve shaker as used to determine the maximum density of cohesionless soils.

APPENDIX C

Characteristics of Vibrators Used to Obtain the Maximum Density of Cohesionless Soils

INTRODUCTION

The maximum density obtained by vibration of a cohesionless soil is believed to depend on the amplitude and frequency of vibration. The purpose of this appendix is to discuss in more detail the characteristics of the vibrators used in this study.

POWER SUPPLY

A 230-volt source was used for the two electromagnetic vibrators. Although these vibrators may be purchased for use with a 115-volt source, the data presented here are probably applicable only when a 230-volt source is used. A 115-volt source was used for the eccentric weight vibrator. Each of the vibrators is equipped with a rheostat by which the power can be varied from 0 to 100 percent.

LOAD-AMPLITUDE RELATIONSHIP

Since the load on the vibrator depends on the maximum grain size of the material being tested, the amplitude was determined for loads between 0 and 300 pounds at various rheostat settings.

The load was applied in increments of 50 pounds by varying the amount of sand in a 0.5-cubic-foot measure and combinations of 20- and 35-pound steelplates. The amplitude was measured at various loads and rheostat settings by a recording-type vibrometer on opposite sides of the measure as shown in Figure C-1. The arrangement of plates and measure for the 250-pound load is shown in Figure C-2. The amplitudes were also measured when the solid 2-psi surcharge weights were used as in an actual test.

The results of amplitude measurements are presented in Tables C-1 and C-2 for Vibrator No. 9, in Table C-3 for Vibrator No. 10, and in Table C-4 for Vibrator No. 11. Selected portions of these data are presented graphically in Figures 10, 11, and 12 in the body of this report. It is evident from these data that the amplitude varies at different points on the measure and on the vibrating table. The reason for these variations is not apparent. Observations during vibration tests indicate that particles tend to migrate from points of high amplitude to points of low amplitude; therefore the variation in amplitude may have a significant effect on the soil density obtained. Further investigation is required to determine the magnitude of this effect.

Table C-1

VARIATION OF AMPLITUDE WITH RHEOSTAT SETTING AND LOAD - LARGE ELECTROMAGNETIC VIBRATOR
 NO. 9. AMPLITUDES MEASURED ON THE HANDLES OF THE 0.5 CUBIC FOOT MEASURE

Rheostat	Load = 0 lbs	Load = 50 lbs	Load = 100 lbs	Load = 150 lbs
Setting	Amplitude, in. <u>1</u> /	Amplitude, in. <u>2</u> /	Amplitude, in. <u>2</u> /	Amplitude, in. <u>2</u> /
	1	2	1	2
30	.013	.011 : .019	.010 : .015	.008 : .010
40	.014	.019 : .014	.011 : .015	.010 : .013
50	.018	.016 : .025	.013 : .016	.013 : .015
60	.023	.019 : .025	.011 : .020	.013 : .017
70	.023	.022 : .027	.017 : .021	.014 : .021
80	.022	.022 : .030	.011 : .021	.011 : .023
90	.027	.023 : .032	.029 : .023	.019 : .023
100	.027	.024 : .033	.017 : .018	.019 : .033
	Load = 200 lbs	Load = 250 lbs	Load = 263 lbs	Load = 300 lbs
	Amplitude, in. <u>2</u> /	Amplitude, in. <u>2</u> /	Amplitude, in. <u>3</u> /	Amplitude, in. <u>3</u> /
	1 : 2	1 : 2	1 : 2	1 : 2
30	.005 : .010	.005 : .008	.004 : .012	.005 : .004
40	.006 : .012	.006 : .007	.006 : .013	.006 : .008
50	.008 : .015	.004 : .010	.007 : .013	.008 : .010
60	.010 : .017	.006 : .010	.008 : .015	.013 : .015
70	.013 : .017	.010 : .010	.005 : .013	.014 : .016
80	.015 : .019	.010 : .011	.005 : .013	.013 : .015
90	.015 : .023	.011 : .015	.006 : .015	.011 : .015
100	.017 : .025	.011 : .015	.006 : .015	.012 : .017
	:	:	:	:

1/Measured in center of table.

2/The amplitudes were measured on opposite sides of the measure at points designated 1 and 2. A combination of loose steel plates, the 0.5 cubic foot measure, and soil were used for this load.

3/A solid 2 piece surcharge weight and the 0.5 cubic foot measure filled with soil were used for this load.

Table C-2

VARIATION OF AMPLITUDE WITH RHEOSTAT SETTING AND LOAD - LARGE ELECTROMAGNETIC VIBRATOR
NO. 9. AMPLITUDES MEASURED ON THE VIBRATOR TABLE

Rheostat :	Load = 0 lbs		Load = 50 lbs		Load = 100 lbs		Load = 150 lbs	
Setting :	Amplitude, in. 1/		Amplitude, in. 2/		Amplitude, in. 2/		Amplitude, in. 2/	
:	1	2	1	2	1	2	1	2
30	.013		.015	.019	.011	.017	.011	.010
40	.017		.014	.021	.015	.016	.015	.015
50	.018		.021	.021	.017	.019	.013	.019
60	.019		.021	.025	.015	.016	.013	.017
70	.021		.025	.026	.022	.022	.013	.019
80	.023		.026	.029	.024	.015	.015	.023
90	.025		.027	.029	.027	.018	.017	.023
100	.029		.030	.033	.017	.025	.023	.033
	Load = 200 lbs		Load = 250 lbs		Load = 263 lbs		Load = 300 lbs	
	Amplitude, in. 2/		Amplitude, in. 2/		Amplitude, in. 3/		Amplitude, in. 3/	
	1	2	1	2	1	2	1	2
30	.008	.009	.006	.006	.006	.003	.006	.008
40	.006	.012	.005	.009	.008	.010	.006	.017
50	.008	.013	.004	.010	.006	.010	.008	.017
60	.010	.011	.008	.009	.009	.015	.008	.021
70	.013	.015	.007	.010	.013	.016	.005	.011
80	.013	.019	.010	.015	.011	.013	.007	.014
90	.014	.021	.010	.015	.012	.017	.005	.015
100	.015	.025	.010	.015	.011	.019	.006	.018
	:	:	:	:	:	:	:	:

1/Measured in center of table.

2/The amplitudes were measured on opposite sides of the table at points designated 1 and 2 located beneath the handles of the 0.5 cubic foot measure. A combination of loose steel plates, the 0.5 cubic foot measure, and soil were used for this load.

3/A solid 2 piece surcharge weight and the 0.5 cubic foot measure filled with soil were used for this load.

Table C-3

VARIATION OF AMPLITUDE WITH RHEOSTAT SETTING AND LOAD - SMALL ELECTROMAGNETIC VIBRATOR NO. 10
AMPLITUDES WERE MEASURED ON THE HANDLES OF THE 0.5 CUBIC FOOT MEASURE

Rheostat : Load = 0 lbs		: Load = 50 lbs		: Load = 90.5 lbs		: Load = 100 lbs		: Load = 150 lbs	
Setting : Amplitude, in. 1/		: Amplitude, in. 2/		: Amplitude, in. 3/		: Amplitude, in. 2/		: Amplitude, in. 2/	
	1	2	1	2	1	2	1	2	
0	.004	.003	.002	.003	.002	.002	.001	.001	.001
10	.010	.004	.004	.004	.002	.002	.002	.002	.003
20	.013	.005	.005	.005	.003	.003	.003	.003	.004
30	.018	.006	.006	.006	.004	.004	.003	.003	.005
40	.021	.010	.010	.010	.008	.006	.004	.004	.007
50	.028	.013	.013	.010	.010	.008	.005	.005	.006
60	.033	.017	.013	.013	.006	.011	.006	.006	.010
70	.038	.021	.017	.017	.019	.005	.010	.010	.012
80	.043	.029	.023	.023	.015	.015	.011	.011	.015
90	.044	.029	.027	.027	.015	.017	.018	.018	.015
100	.046	.029	.021	.019	.023	.017	.017	.017	.015
: Load = 200 lbs		: Load = 250 lbs		: Load = 264 lbs		: Load = 300 lbs			
: Amplitude, in. 2/		: Amplitude, in. 2/		: Amplitude, in. 3/		: Amplitude, in. 3/			
	1	2	1	2	1	2	1	2	
0	.001	.002	.002	.001	.001	.001	.001	.001	.001
10	.002	.004	.002	.003	.001	.001	.001	.002	.002
20	.002	.006	.002	.004	.001	.001	.001	.003	.003
30	.003	.007	.002	.004	.002	.002	.003	.003	.003
40	.002	.009	.003	.008	.002	.002	.003	.003	.003
50	.003	.010	.003	.008	.002	.003	.006	.006	.006
60	.003	.011	.004	.008	.002	.004	.007	.007	.007
70	.008	.019	.003	.013	.003	.005	.009	.009	.009
80	.009	.019	.003	.013	.005	.006	.016	.016	.016
90	.011	.019	.003	.018	.004	.008	.019	.019	.019
100	.010	.023	.008	.015	.003	.004	.015	.015	.015
1/Measured in center of table.									

2/The amplitudes were measured on opposite sides of the measure at points designated 1 and 2. A combination of loose steel plates, the 0.5 cubic foot measure, and soil were used for this load.

3/A solid 2 psi surcharge weight and the 0.1 cubic foot measure filled with soil were used for this load. Amplitudes were measured on opposite side of the 0.1 cubic foot measure.

4/A solid 2 piece surcharge weight and the 0.5 cubic foot measure filled with soil were used for this load.

Table C-4

VARIATION OF AMPLITUDE WITH RHEOSTAT SETTING AND LOAD - ECCENTRIC WEIGHT MOTOR VIBRATOR NO. 11.
AMPLITUDES WERE MEASURED ON THE HANDLES OF THE 0.5 CUBIC FOOT MEASURE

Rheostat	Load = 0 lbs	Load = 50 lbs	Load = 90.4 lbs	Load = 100 lbs	Load = 150 lbs
Setting volts:	Amplitude, in. 1/	Amplitude, in. 2/	Amplitude, in. 3/	Amplitude, in. 2/	Amplitude, in. 2/
40	.011	.004	.008	.001	.001
50	.011	.007	.015	.005	.005
60	.017	.008	.007	.004	.004
70	.019	.008	.008	.005	.004
80	.011	.008	.006	.004	.004
90	.010	.007	.005	.005	.005
100	.009	.008	.006	.005	.004
110	.008	.008	.008	.005	.005
120	.007	.008	.008	.005	.005

Rheostat	Load = 200 lbs	Load = 250 lbs	Load = 264 lbs	Load = 300 lbs
Setting volts:	Amplitude, in. 2/	Amplitude, in. 2/	Amplitude, in. 4/	Amplitude, in. 2/
40	.003	.004	.003	.002
50	.003	.004	.003	.002
60	.003	.003	.002	.001
70	.002	.002	.002	.001
80	.003	.002	.002	.001
90	.003	.002	.002	.001
100	.004	.002	.004	.001
110	.006	.003	.005	.001
120	.006	.004	.006	.002

1/Measured in center of table

2/The amplitudes were measured on opposite sides of the measure at points designated 1 and 2. A combination of loose steel plates, the 0.5 cubic foot measure, and soil were used for this load.

3/A solid 2 psi surcharge weight and the 0.1 cubic foot measure filled with soil were used for this load. Amplitudes were measured on opposite sides of the 0.1 cubic foot measure.

4/A solid 2 piece surcharge weight and the 0.5 cubic foot measure filled with soil were used for this load.



Recording-type vibrometer used to
measure amplitude of vibration



Photograph of weights used to determine the effect
of load on the amplitude of vibration

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil.	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
.	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
.	0.3048 (exactly)*	Meters
.	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
.	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
.	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
.	4,046.9*	Square meters
.	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
.	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
.	0.473166	Liters
Quarts (U.S.)	9.46358	Cubic centimeters
.	0.946358	Liters
Gallons (U.S.)	3.78543*	Cubic centimeters
.	3.78543	Cubic decimeters
.	3.78533	Liters
.	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
.	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
.	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain	Multiply	By	To obtain
MASS					
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams	Pounds	0.453592*	Kilograms
Troy ounces (480 grains)	31.1035	Grams		4.4482*	Newtons
Ounces (avdp)	28.3495	Grams		4.4482 x 10 ⁻⁵ *	Dynes
Pounds (avdp)	0.45359237 (exactly)	Kilograms	WORK AND ENERGY*		
Short tons (2,000 lb)	907.185	Kilograms	British thermal units (Btu)	0.252*	Kilogram calories
Long tons (2,240 lb)	0.907185	Metric tons	Btu per pound	1,055.06	Joules
	1.01605	Kilograms	Foot-pounds	2.32 (exactly)	Joules per gram
				1.35582*	Joules
FORCE/AREA					
Pounds per square inch	0.070307	Kilograms per square centimeter	POWER		
Pounds per square foot	0.689476	Newtona per square centimeter	Horsepower	745.700	Watts
	4.88243	Kilograms per square meter	Btu per hour	0.293071	Watts
	47.8803	Newtona per square meter	Foot-pounds per second	1.35582	Watts
MASS/VOLUME (DENSITY)					
Ounces per cubic inch	1.72999	Grams per cubic centimeter	HEAT TRANSFER		
Pounds per cubic foot	16.0185	Kilograms per cubic meter	Btu in./hr ft ² deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.0160185	Grams per cubic centimeter	Btu ft/hr ft ² deg F	0.1240	Kg cal/hr m deg C
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter	Btu/hr ft ² deg F (C, thermal conductance)	1.4880*	Kg cal m/hr m ² deg C
MASS/CAPACITY			Deg F hr ft ² /Btu (R, thermal resistance)	0.568	Milliwatts/cm ² deg C
Ounces per gallon (U.S.)	7.4893	Grams per liter	Btu/lb deg F (c, heat capacity)	4.882	Kg cal/hr m ² deg C
Pounds per gallon (U.S.)	6.2362	Grams per liter	Btu/lb deg F	1.761	Deg C cm ² /milliwatt
Pounds per gallon (U.K.)	119.829	Grams per liter	ft ² /hr (thermal diffusivity)	4.1868	J/g deg C
Pounds per gallon (U.K.)	99.779	Grams per liter		1.000*	Cal/gram deg C
BENDING MOMENT OR TORQUE				0.2581	cm ² /sec
Inch-pounds	0.011521	Meter-kilograms		0.09290*	N ² /hr
Foot-pounds	1.12985 x 10 ⁶	Centimeter-dynes	WATER VAPOR TRANSMISSION		
	0.138255	Meter-kilograms	Grains/hr ft ² (water vapor transmission)	16.7	Grams/24 hr m ²
Foot-pounds per inch	1.35582 x 10 ⁷	Centimeter-dynes	Perms (permeance)	0.659	Metric perms
Ounce-inches	5.4431	Centimeter-kilograms per centimeter	Fern-inches (permeability)	1.67	Metric perm-centimeters
	72.006	Gram-centimeters	OTHER QUANTITIES AND UNITS		
VELOCITY					
Feet per second	30.48 (exactly)	Centimeters per second	Multiply	By	To obtain
Feet per year	0.3048 (exactly)*	Meters per second	Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Miles per hour	0.965873 x 10 ⁻⁶ *	Centimeters per second	Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
	1.609344 (exactly)	Kilometers per hour	Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
	0.44704 (exactly)	Meters per second	Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
ACCELERATION*			Volts per mil	0.03937	Kilovolts per millimeter
Feet per second ²	0.3048*	Meters per second ²	Lumens per square foot (foot-candles)	10.764	Lumens per square meter
FLOW			Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Cubic feet per second (second-foot)	0.028317*	Cubic meters per second	Milliampes per square foot	35.3147*	Milliampes per square meter
Cubic feet per minute	0.4719	Liters per second	Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons (U.S.) per minute	0.06309	Liters per second	Callons per square yard	4.527219*	Liters per square meter
			Pounds per inch	0.17859*	Kilograms per centimeter